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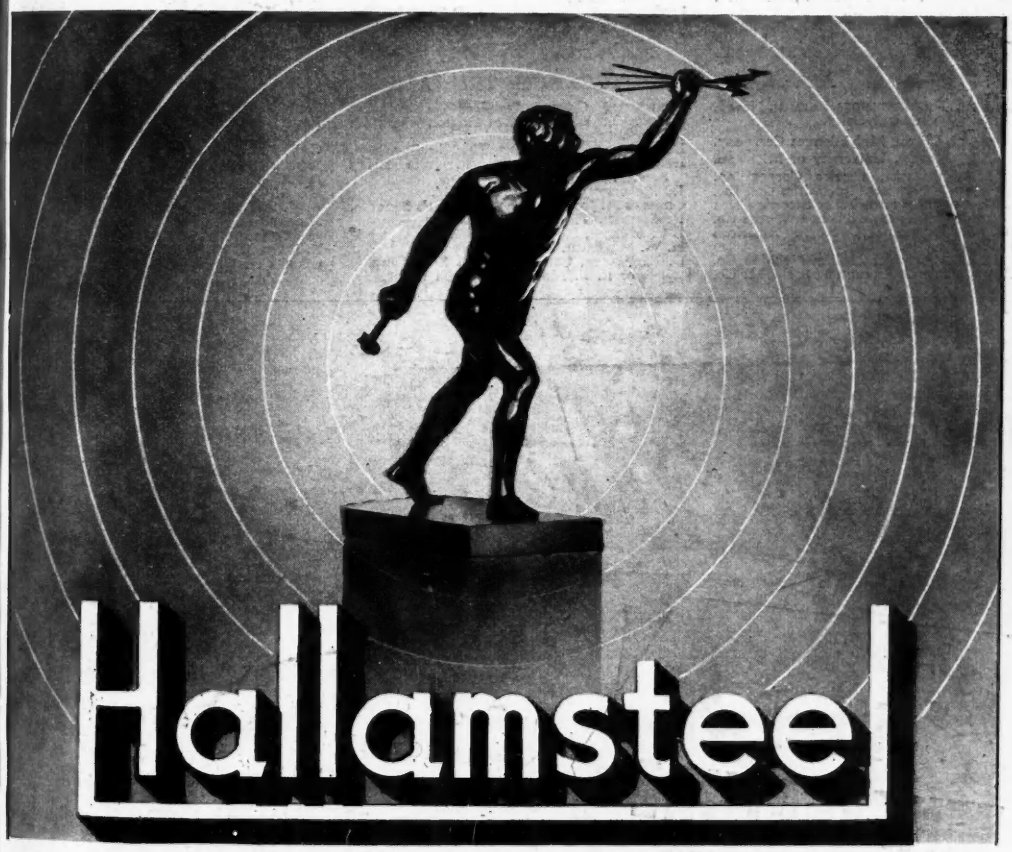

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The Future of Atomic Power

By R. Tom Sawyer. (From *The Engineers' Digest*, American Edition, Vol. 4, No. 7, p. 302.)

I have been asked to sketch in broad outline the future of atomic power. Much speculative writing has been published since the first atomic bomb was dropped almost two years ago. Some of this has been the result of critically analytical thinking by reputable scientists and engineers, but the effect of this has been nullified to a certain extent by the volume of imaginative flights of fancy by sensationalists. This, then, is an attempt to sift the probable from the improbable.

I will not undertake here a discussion of what atomic power is, nor do I think it necessary. The atomic chain reaction units now in operation, about which the basic facts have been published, prove that energy of the atomic nucleus can be effectively harnessed and controlled. This makes atomic power an economic possibility that will, I think, be realized at least on an experimental scale within the next decade. It is probable that the first atomic energy power plants will be of the chain reaction type, and that power will be derived from them in the form of heat given off by atomic fission and added to the cooling agent of the chain reaction unit. The heated cooling fluid would be passed in heat exchange relationship with air, water, helium, mercury, or some other fluid, which would in turn be used for space heating, drying or processing ; or converted into mechanical energy by using it to drive steam engines or turbines, open or closed-cycle gas turbines, or mercury vapour turbines.

It seems fairly certain that the first commercial application of atomic power will be electricity-generating power stations. The capacity of such a pioneer station would be about 75,000 kw. Smaller units do not look practical at this time because of the massive shielding necessary to safeguard personal from dangerous radiation. The atomic fuel for such a power station would be normal uranium (0·7 per cent U-235), enriched somewhat by the addition of more U-235 if the prime mover were of the gas turbine type, since gas turbine efficiencies increases as the inlet temperature increases. Quite apart from the increases in first cost as the degree of enrichment is increased, enrichment of the atomic fuel past 5 per cent U-235 will probably not be considered desirable due to the difficulty of removing large amounts of energy rapidly from small spaces. A study has been made of the cost of nuclear power produced by a modified Hanford type pile, based on data now available. This study indicated that this type of plant would have the same operating costs as existing coal-fired plants, if coal cost $10.00 a ton. It should be emphasized that this study was based on present available data. There is no doubt that lower costs of nuclear power plants will be realized as a result of continuing research and development. And the trend of coal and fuel oil prices has been steadily upward. Standardization of design and construction would materially reduce both first cost and operating cost of atomic plants.

The inherent production of valuable by-products such as radioactive isotopes and fission products could also drop the cost of the power produced.

Even with the cost of coal lower than $10.00 a ton, atomic power plants would be advantageous in many applications. They are eminently suitable for stand-by units due to the ease and flexibility with which the rate of power production can be controlled. Industry could be decentralized, a desirable feature in itself, and one which would also decrease power transmission losses and costs. Isolated areas, where large quantities of water are not available, and where difficulty of transportation makes fuel costs prohibitive, could be developed, since the weight of the uranium fuel is insignificant in comparison with the amount of heat energy contained therein and the rate of fuel consumed in relation to the amount of power produced is fantastically low.

Naturally, there are disadvantages to the use of atomic power plants to partially offset the above-mentioned advantages. The necessary heavy protective shields are one, and the increase in operation costs due to the necessity of careful supervision by experts familiar with the radiological hazards involved is another. Probably the most troublesome disadvantage is that of the chemical treatment necessary to purify and fabricate the uranium charge. Notwithstanding the disadvantages involved, the advantages gained by the use of atomic power plants in the above-mentioned applications will probably assure their adoption. I should pause right here to say that all of this discussion presupposes the solution of many difficult technological problems. Many of these are being solved now by research engineers and physicists, and since the problems appear difficult rather than impossible I think it is fair to assume their solution in the near future.

The construction of an atomic-powered ship seems likely to be the next step after building an atomic power plant. For several reasons it is probable that this will be a naval vessel ; because the shielding that is necessary can also be used as armour plate, because there will be no smoke, and because range of operation without refuelling is of more importance to the Navy than the " pay load." An atomic power plant in this application will have plenty of water available for cooling purposes, and it is conceivable that in time it could be operated so as to produce fission material for making its own atomic bombs " on location."

Looking a little further into the future, we see the possibilities of atomic powered locomotives. Before these can become a commercial possibility, the weight and bulk of the shielding required for safe operation of the atomic power unit must be reduced to a point where it can go on existing road beds, bridges, and turntables, and through existing tunnels and roundhouse doors. When this has been accomplished, we will probably find both the steam and the gas turbine locomotives powered with atomic fuel. At about the same time, we will probably find very large aircraft, which have weight and space problems similar to those of a locomotive, atomic powered. At this time it does not seem that smaller aircraft or automobiles can be driven by atomic power, both because of the shielding difficulties, and because there is a limit to the mass of fission material below which a chain reaction is not self-sustaining. But the atomic age is still so young that it would be a foolish man indeed who said that an atomic powered automobile was impossible.

Further ahead in the future lie such possibilities as atomic powered rocket ships for interplanetary travel, and the production of electricity directlv from a uranium pile by collecting, directing, and controlling the electrons given off in the fission process. The atomic age has just begun.

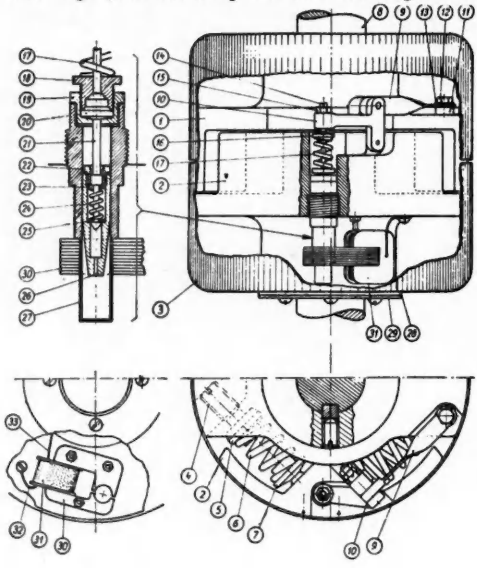
SWEDEN

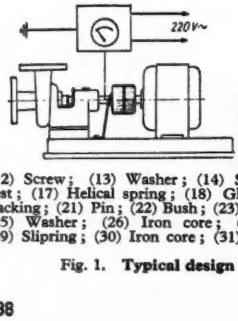
Device for Measuring Torque

By A. MOERTSELL. (From *Teknisk Tidskrift*, Vol. 77, No. 20, May 17, 1947, pp. 437–438, 6 illustrations.)

THE device described by the author was developed for the purpose of facilitating measurement of the torque transmitted from one rotating shaft to another. It consists of a flexible coupling interposed between the driving and the driven shaft. The torque transmitted by the coupling is indicated in linear relationship by an electrical instrument. As the indication is purely static and not therefore dependent upon the speed of the shaft, calibration of the torque indicator can be effected when it is at rest. In many cases it is desirable to eliminate vibrations and to measure the mean effective torque ; for this purpose the apparatus is fitted with a damping device which eliminates vibrations with frequencies down to one cycle per second.

The design shown in Fig. 1 is suitable for shaft speeds up to 3,000 r.p.m. The coupling consists of two halves (1) and (2) affixed to the respective shaft ends. The two coupling halves are coupled by means of the springs (6) and the flexible link (9). The springs (6) absorb the torque, while the link (9) transmits the torsional displacement of the two coupling halves to a lever (10) which in turn displaces the spring rest (16) in direct proportion with the torsional displacement. The sensitive element for measuring the displacement, and with it the torque, is attached to the aforementioned spring rest (16). As will be seen from Fig. 1, the movable part of the measuring element





(1) (2) Coupling halves ; (3) Casing ; (4) Adjusting screw ; (5) Spring rest ; (6) Helical spring ; (7) Spring rest ; (8) Shaft ; (9) Flexible link ; (10) Lever ; (11) Distance piece ; (12) Screw ; (13) Washer ; (14) Screw ; (15) Nut ; (16) Spring rest ; (17) Helical spring ; (18) Gland ; (19) Stuffing box ; (20) Packing ; (21) Pin ; (22) Bush ; (23) Washer ; (24) Damper spring ; (25) Washer ; (26) Iron core ; (27) Well ; (28) Mica plate ; (29) Slipring ; (30) Iron core ; (31) Coil ; (32) (33) Electric leads.

Fig. 1. Typical design of torque indicator.

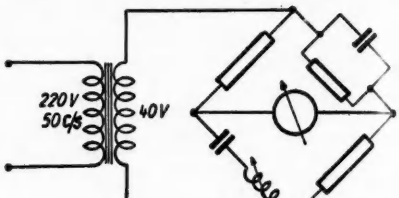


Fig. 2. Instrument circuit.

consists of an iron core (26) which by means of pin (21) is attached to part (16) and lever (10). For damping purposes the armature (26) is connected with pin (21) by means of a spring.

The indication of the torque can be carried out by several methods. Electric methods are particularly convenient, as these enable the indicating instrument to be installed at any distance from the machines to which the coupling is fitted. The relative displacement of the coupling halves may be utilized for varying the electrical resistance, capacity, or self-induction, the latter method being employed in the coupling shown in Fig. 1. Here the self-induction consists of a coil (31) and a core (30); and it will be noted that the core has an air gap the width of which is given by the position of the iron core (26) and consequently by the mutual displacement of the two coupling halves. The well (27) in which (26) is located must be made of non-magnetic material, and in this instance is made of brass. The bridge circuit employed for the electrical indicating instrument is shown in Fig. 2. Owing to the conical shape of piece (26) the deflection of the electrical instrument is directly proportional to the displacement of (26), that is, it is also directly proportional to the torque.

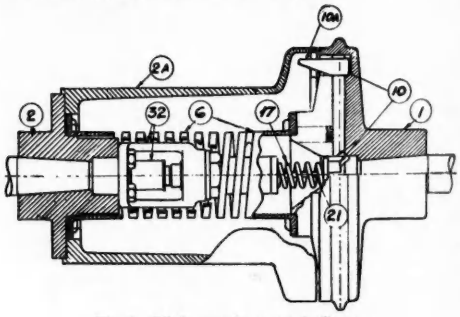


Fig. 3. High speed torque indicator.

Fig. 3, shows a similar coupling for high speed. Here (1) and (2) are the coupling ends ; the turning moment is transmitted by the spring (6). The angular displacement is transmitted from the casing (2A) via the lever and shaft (10) to the pin (21) which in turn actuates the sending element which is axially slidable in the concentrically arranged solenoid (32). It is expected that with this design dynamic balance can be achieved even at high rotational speed. A torque indicator of this type is fitted to an emulsifier at the Rubber Laboratory at Uppsala where it is giving satisfactory service. In this installation the indicating instrument is placed at a distance of 15 m. from the coupling itself.

Stabilization of Synchronous Generators by Rapid Regulation of Excitation in Power Transmission Over Long Distances

By W. FREY. (From *Brown Boveri Mitteilungen*, Vol. 33, No. 11, November, 1946, pp. 335-347, 8 illustrations.)

STATIC compensation with reactors, by means of which the characteristic data of a line can be varied at will, is only effective for a given operating frequency. In principle the reactance of the entire line can be compensated[1,2]. This method is extremely simple but not very economical; moreover capacitive power cannot be so easily provided by phase changers.

The question forming the subject of this investigation is whether the stability difficulties can be overcome by means of electric power generators of modified design. The first possibility is to use asynchronous generators[3]; the other, which will be examined in this article, is to improve stability by achieving a very rapid regulation of the excitation in synchronous generators. The influence of the regulator will be taken account of by using, instead of the synchronous reactance, a smaller pendulous reactance in the calculations in order to obtain what is known as an artificial stabilization of the synchronous machine[4,5,6,7].

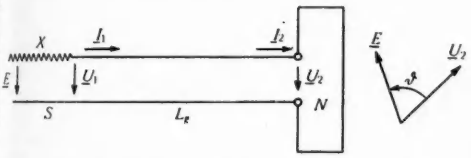


Fig. 1. **Schematic diagram of the investigated arrangement.**

I. PRINCIPLE OF THE ARTIFICIAL STABILIZATION.

A synchronous machine S (Fig. 1) delivers electrical energy through a power line Lg to an infinitely strong network N. The machine will be assumed to have solid drum-type rotors, and the stator and line losses will be neglected. The machine is then fully characterized for stationary phenomena by its synchronous reactance X and the pole wheel voltage $\mathbf{E}$.* The line is determined by its wave resistance Z and its electric length Φ[8]. If ϑ is the pole-wheel angle, i.e., the angle between the voltage $\mathbf{U}_2$ of the network N and the pole voltage $\mathbf{E}$, then it can easily be shown that the effective power P_W delivered by the machine is given by

$$P_W = \frac{3\,U_2 E}{X'} \sin \vartheta,$$

where $$X' = X \cos \Phi + Z \sin \Phi.$$

X' will always be positive provided we confine ourselves to line lengths corresponding to a pole-wheel angle which is less than 90 deg., i.e., less than 1,500 km. at 50 cycles/sec., which is the stability limit. Thus the relationship between ϑ and the effective power supplied is in principle the same with the machine on the line or on a rigid network. Consequently, for economic transmission the power to be transmitted can be about twice as great as the natural power P_N of the line. In this case the angle between the voltages at the beginning and the end of the line is exactly equal to the electric line length Φ[8]. The pole-wheel angle ϑ is then equal to $\Phi + \alpha$. If the nominal power of the machine coincides more or less with the natural power, then the value of α can be estimated at 45–60 deg. Thus even with line lengths of a few hundred kilometres ϑ will reach values which are dangerously near the stability limit. Practical experience has shown, however, that the simplified theory with constant pole-wheel voltage E gives results which are too pessimistic as regards stability. This is because the effect of the voltage regulator has been neglected, for as soon as this starts operating, the pole-wheel voltage is no longer constant.

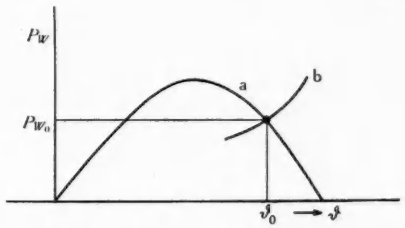


Fig. 2. **Effective power as a function of the pole-wheel angle ϑ.**

To study the principle which forms the basis of this problem, it will be assumed that the regulator will regulate the excitation as a function of the pole-wheel angle ϑ. The effective power of the machine will then no longer be a sine-type function of ϑ, but will be determined by the pole-wheel voltage E. In Fig. 2, curve a shows the variation of effective power with a non-regulated machine and curve b a variation which can be obtained by suitable regulation. If it were possible to maintain the relationship between ϑ and E indicated in Fig. 2 during the rapidly occurring compensating processes, then the machine would be stable at the working point P_{W0}, ϑ_0 in spite of the fact that $\vartheta_0 > 90$ deg. Obviously, this is not generally the case, but by considering Fig. 2 it will be possible to formulate a necessary condition for artificial stabilization to be achieved.

Assuming that a small change $\Delta\vartheta$ of the pole-wheel angle ϑ corresponds to a small change Δu of the excitation voltage u, we can relate Δu to the excitation u_0 for stationary operation by means of the ratio $\xi_5 = \Delta u/u_0$; ξ_5 can then be assumed to vary as a linear function of $\Delta\vartheta$, so that $\xi_5 = K\,\Delta\vartheta$. For the non-regulated machine, $K = 0$. When $\vartheta_0 > 90$ deg., a minimum value of K can easily be given to indicate when stabilization is necessary. For efficient stabilization the effective power in the vicinity of the working point must increase when the value of ϑ increases. Therefore this gives the condition $dP_W/d\vartheta > 0$. Hence with $P_W = 3U_2 E \cdot \sin\vartheta/X'$ it follows that

$$E \cos \vartheta_0 + \frac{dE}{d\vartheta} \sin \vartheta_0 > 0.$$

For stationary operating conditions, when saturation is neglected, the pole-wheel voltage E is proportional to the excitation voltage, so that we can write $\Delta u/u = \Delta E/E = \xi_5$. Hence, with $dP_W/d\vartheta > 0$, after replacing differentials by differences, we have

$$\xi_5 + \operatorname{cotan} \vartheta_0 \Delta\vartheta > 0.$$

On comparing with $\xi_5 = K\,\Delta\vartheta$ this gives

$$K > \left| \operatorname{cotan} \vartheta_0 \right|$$

*Vector quantities are denoted by bold letters in the text and by underlined letters in the figures.

This is a necessary condition for artificial stabilization ; it will be referred to as the " static condition," as it has been obtained without considering the electrodynamic compensating processes. The problem is now to find the conditions which have to be added to the above inequality for K, in order to set up a system of necessary and sufficient conditions for stability. The theory will show that in spite of the large time-constants involved, by altering the value of the rotor current, it will be possible to fulfil these conditions without great difficulty.

II. BASIC EQUATION OF THE MACHINE ON A RIGID NETWORK.

This simplified case will serve to illustrate the various aspects of the problem and to show how the transition to the machine on the power-line can be obtained by merely adjusting some of the constants.

The frequency of the compensating processes will be assumed to be small compared with network frequency. This means that at any instant, even during the compensating processes, the corresponding vector diagram for the stator currents and voltages will be valid. The rotor will be assumed to have one winding about each axis. The winding on the transverse axis will also be led towards the outside by means of slip-rings, and therefore it will also be possible to excite it according to requirements. To simplify calculations the stator will moreover be a two-phase winding ; this does not affect the practical problem since a two-phase winding also generates a rotary field in the stator.

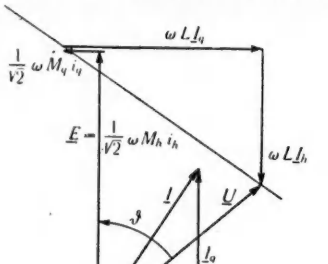


Fig. 3. **Vector diagram of the machine on a rigid network.**

The following equations can be derived from the vector diagram of the machine, shown in Fig. 3 :

$$\left.\begin{aligned} U\cos\vartheta &= \frac{1}{\sqrt{2}}\omega M_h i_h - \omega L I_h \\ U\sin\vartheta &= \frac{1}{\sqrt{2}}\omega M_q i_q + \omega L I_q \end{aligned}\right\} \quad (1)$$

where $\mathbf{U}$ = network voltage ; M_h, M_q = mutual inductances of rotor and stator ; i_h, i_q = rotor currents ; L = self-inductance of the stator winding ; I_h, I_q = components of stator current in the directions of the main axis and the transverse axis. Furthermore, the following equations are valid for the rotor (with $p = \frac{d}{dt}$):

$$\left.\begin{aligned} u_h &= r_h i_h + p l_h i_h - p M_h I_h \sqrt{2} \\ u_q &= r_q i_q + p l_q i_q - p M_q I_q \sqrt{2} \end{aligned}\right\} \quad (2)$$

where l_h, l_q and r_h, r_q are the self-inductances and the resistances of the rotor windings. Fig. 3 shows that the torque developed by the currents is

$$M_{el} = -\sqrt{2}\,(M_h i_h I_q - M_q i_q I_h) \quad (3)$$

Let M_o be the driving torque of the primary machine, which will be regarded as constant ; the equation for the motion of the rotor is then :

$$\mathfrak{J}_p{}^2 \vartheta = -\sqrt{2}\,(M_h i_h I_q - M_q i_q I_h) + M_o \quad (4)$$

$\mathfrak{J}_p$ is the moment of inertia of the two-pole machine. If the machine is not of the two-pole type, its inertia should be divided by the square of the number of pole pairs. Assuming u_h and u_q are known, equations (1), (2) and (4) are sufficient to determine the five unknowns I_h, I_q, i_h, i_q and ϑ. The general treatment of the system of equations cannot be continued further owing to mathematical difficulties, so that the investigation will be confined to small deflections for which the system becomes a linear system. For this each of the variables will be written as a sum of a stationary value and a small deviation from this value. Thus :

$$\left.\begin{aligned} &i_h = i_{ho} + x_1, \qquad I_h = I_{ho} + x_2, \\ &I_q = I_{qo} + x_3, \qquad i_q = i_{qo} + x_4\,(i_{qo} = 0), \\ &\vartheta = \vartheta_o + x_5\,(x_5 = \Delta\vartheta),\ u_h = u_{ho} + x_6, \\ &u_q = u_{qo} + x_7\,(u_{qo} = 0). \end{aligned}\right\} \quad (5)$$

u_{qo} and i_{qo} are zero because it was assumed that the voltage of the transverse winding of the rotor is zero in the stationary condition. The possibility of exciting this winding will only be used for artificial stabilization. The expressions (5) can now be put into equations (1), (2) and (3). Omitting the subscripts for simplicity except in the case of ϑ_o, we obtain the following linear system of equations :

$$\left.\begin{aligned} 0 &= \frac{1}{\sqrt{2}}\omega M_h x_1 - \omega L x_2 + U\sin\vartheta\, x_5 \\ 0 &= \omega L x_3 - \frac{1}{\sqrt{2}}\omega M_q x_4 - U\cos\vartheta\, x_5 \\ x_6 &= (r_h + p l_h)\, x_1 - \sqrt{2}\, M_h p x_2 \\ x_7 &= -\sqrt{2}\, M_q p x_3 + (r_q + p l_q)\, x_4 \\ 0 &= \sqrt{2}\, M_h I_q x_1 + \sqrt{2}\, M_h i_{ho} x_3 - \\ &\qquad -\sqrt{2}\, M_q I_h x_4 + p^2 \mathfrak{J} x_5. \end{aligned}\right\} \quad (6)$$

This is an inhomogeneous system of ordinary differential equations, which can be solved by assuming that the disturbance terms are of the form

$$x_6 = X_6\, e^{pt} \text{ and } x_7 = X_7\, e^{pt} \quad (7)$$

so that for $i = 1$ to 5, we shall also have

$$x_i = X_i\, e^{pt} \quad (8)$$

The system of characteristic equations obtained by substituting (7) and (8) in (6) is identical with the system (6), the only difference being that p now has the character of an ordinary algebraic quantity and that X_i is used instead of x_i. We can first calculate by means of determinants the value of X_5 as a function of X_6 and X_7 :

$$X_5 = -\tau_h' \sin\vartheta_o \frac{p+\tau_q'}{Q(p)}\,\xi_6 - \tau_q' \cos\vartheta_o \frac{M_q}{M_h}\frac{r_h}{r_q}\frac{p+\tau_h'}{Q(p)}\,\xi_7 \quad (9)$$

where the following abbreviations have been used :

$\xi_6 = X_6/u_h$, $\xi_7 = X_7/u_h$ (voltage variation in the excitation circuit relative to the stationary excitation voltage),

$T_{h,q} = l_{h,q}/r_{h,q}$ = zero load time-constants,

$\tau_h', \tau_q' = 1/T_h', T_q'$, $\Omega^2 = 2UE/\omega^2 L\mathfrak{J}$ (Ω = circular frequency of the electromechanical oscillations of the machine for $\vartheta = 0$)

$\sigma_{h,q} = 1 - (M^2_{h,q}/Ll_{h,q}) =$ stray field coefficients

$$A_h = \frac{U}{E}\,\frac{1-\sigma_h}{\sigma_h}\sin^2\vartheta, \qquad A_q = \frac{U}{E}\,\frac{1-\sigma_q}{\sigma_q}\cos^2\vartheta,$$

$$Q(p) = \frac{p^2}{\Omega^2}(p+\tau_h')(p+\tau_q') + A_h p(p+\tau_q') + A_q p(p+\tau_h') + \cos\vartheta_o\,(p+\tau_h')(p+\tau_q') \quad (10)$$

In the case of an ordinary synchronous machine in which the transverse winding is not excited, we have $\xi_7 = 0$.

III. STABILITY OF THE ORDINARY MACHINE WITHOUT EXCITATION IN THE TRANSVERSE AXIS.

The effect of regulation, which has not yet been introduced into the calculation, is to bring about a functional relationship between ξ_6 and $\Delta\vartheta$. It will be shown later that a regulation which is based on the equation $\xi_5 = K.\Delta\vartheta$ is not sufficient for all cases, and therefore it will be necessary to generalize this equation by making ξ_5 dependent not only on $\Delta\vartheta = x_5$, but also on the velocity $d\Delta\vartheta/dt = p\Delta\vartheta = px_5$ with which the pole-wheel moves away from the equilibrium position. The equation will therefore be :

$$\xi_6 = (K_1 + pK_2)\,X_5 \qquad .. \quad (11)$$

The term $pK_2.X_5$ will be referred to as " slip-controlled regulation," while the first term will be the " angle-controlled regulation." Putting (11) into (9), and remembering that $\xi_7 = 0$, we obtain :

$$X_5\left(1 + \tau_h'\sin\vartheta_o\,\frac{(p+\tau_q')(K_1+pK_2)}{Q(p)}\right) = 0 \quad (12)$$

One of the two factors in (12) must be equal to zero. If $X_5 \neq 0$, then this means that the regulated machine oscillates freely about the equilibrium position. By equating the second factor to zero, we then obtain from (12) the characteristic equation of the system. This equation determines those values of p in the exponential expressions (7) and (8) which exist in the case of free vibrations[9]. For the discussion it will first be assumed that the machine has no transverse winding, i.e., that $\tau_q' = \infty$. After taking the limit value of (12) and making a further transformation, the characteristic equation can be rewritten in the polynomial form :

$$\frac{p^3}{\Omega^2} + \tau_h'\frac{p^2}{\Omega_2} + (\cos\vartheta_o + A_h + K_2\tau_h'\sin\vartheta_o)\,p + \tau_h'(\cos\vartheta_o + K_1\sin\vartheta_o) = 0 \qquad .. \quad .. \quad (13)$$

From (13) we can immediately see whether the regulated machine is stable or not when the pole-wheel angle is ϑ_o. For stability the real parts of all the roots of equation (13) should have a negative value. By applying Hurwitz's criterion[10] the positive or negative character of these roots can be determined directly from the coefficients, without finding the value of each root. According to Hurwitz's theorem, the cubic corresponding to the characteristic equation,

$$c_0p^3 + c_1p^2 + c_2p + c_3 = 0$$

will be stable, provided : (1) that all the $c_k'\,(k = 0, \ldots, 3)$ are of the same sign ; and (2) that $c_1\,c_2 - c_0\,c_3 > 0$. Thus stability will depend on the following conditions :

$$\left.\begin{array}{l}(a)\ \cos\vartheta_o + K_1\sin\vartheta_o > 0,\\ (b)\ A_h + \cos\vartheta_o + \tau_h'K_2\sin\vartheta_o > 0,\\ (c)\ A_h + \sin\vartheta_o(K_2\tau_h' - K_1) > 0.\end{array}\right\} \quad (14)$$

These equations show that there are three cases which should be distinguished :

Case α : $\cos\vartheta_o > 0$ and $A_h + \cos\vartheta_o > 0$;
Case β : $\cos\vartheta_o < 0$ and $A_h + \cos\vartheta_o > 0$;
Case γ : $\cos\vartheta_o < 0$ and $A_h + \cos\vartheta_o < 0$.

From the equation :

$$A_h + \cos\vartheta_K = 0 \qquad .. \quad .. \quad (15)$$

a critical angle $\vartheta_K > 90$ deg. can be determined, so that the three cases can be written as follows :

Case α : $\vartheta_o < 90$ deg. ;
Case β : 90 deg. $< \vartheta_o < \vartheta_K$;
Case γ : $\vartheta_K < \vartheta_o < 180$ deg.

In case α, in principle, no regulation is needed. In case β, stabilization can be obtained without using a regulation depending on slip, hence $K_2 = 0$. K_1 is then required to fulfil the following condition for stability :

$$|\ \text{cotan}\,\vartheta_o\ | < K_1 < A_h/\sin\vartheta_o \qquad .. \quad (17)$$

The minimum value of K_1 is the same as when using the static condition $K > |\ \text{cotan}\,\vartheta_o\ |$. If the upper limit is exceeded it can be shown that the system will start vibrating with increasing amplitudes. This over-regulation can be avoided without using any extra power. Therefore in the case β the static condition will in practice also be a sufficient condition.

In case γ, the inequality (14) shows that the use of a slip-controlled regulation is essential. For K_2 we then have the condition :

$$\left|K_2\right| > T_h'\cdot\left|\frac{A_h + \cos\vartheta_o}{\sin\vartheta_o}\right| \qquad .. \quad (18)$$

Furthermore, condition (14c) must also be considered. An entirely new type of regulation will therefore be necessary in this case, requiring a considerable amount of additional power.

In practice, however, there will not be a great difference between the requirements of cases β and γ. If the working angle ϑ_0 in case β is only slightly below the critical angle ϑ_K, the permissible region for K_1 may become so small that in order to obtain a sufficient margin, slip-controlled regulation will also be required.

The calculations so far made referred to a machine without a winding in the transverse axis, and were based on the assumption that $\tau_q' \gg \tau_h'$. In principle the investigation of the more general case is possible in the same manner, with the aid of equations (9) and (10). The winding in the transverse axis will be favourable for artificial stabilization because it counterbalances the tendency of hunting in case of over-regulation.

IV. PHYSICAL INTERPRETATION OF RESULTS.

A good idea of the physical phenomena involved can be obtained by first considering an ideal machine without rotor resistance, and confining the considerations to a machine without a winding in the transverse axis. It will be assumed that the machine is not regulated, hence $u_h = 0$. From the first relation of equations (2) we obtain : $p\,(l_hi_h - M_hI_h\sqrt{2}) = 0$. The expression within the brackets is therefore constant, and this only expresses the fact that the flux-linkage of the pole-wheel winding remains constant during all processes. The differential equation (2) has thus become an ordinary equation. Using equations (1) we can now calculate the current i and therefore the pole-voltage $\mathbf{E}$ as functions of ϑ. Assuming for this purpose that the pole-wheel has been shifted from a stationary condition ϑ_o through an angle $\vartheta - \vartheta_o$, if E_o is the absolute value of the pole-wheel voltage in the initial condition, then after a few transformations we find that

$$\mathbf{E} = \frac{\mathbf{U}}{U}.e^{j\vartheta}\cdot\left[E_o + U\,\frac{1-\sigma_h}{\sigma_h}\,(\cos\vartheta_o - \cos\vartheta)\right] \quad (19)$$

The absolute value of this vector $\mathbf{E}$ is no longer con-

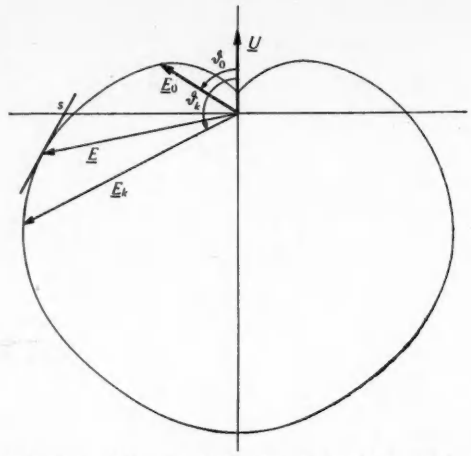


Fig. 4. **Locus of the pole-wheel voltage E of an ideal machine without resistance.**

stant, as was the case with the non-regulated machine with rotor resistance. The curve representing the locus of **E** for a particular case is given in Fig. 4. As **E** is not constant, the stability limit is no longer at $\vartheta = 90$ deg. but at the point where the tangent to the curve is parallel to **U**. The corresponding angle can easily be calculated from the maximum effective power. It will be found that the critical angle is given by : $A_k + \cos\vartheta = 0$. The stability limit of the ideal machine without rotor resistance is not therefore given by $\vartheta = 90$ deg. but by the angle ϑ_K of equation (15). This improvement in stability can be explained as follows : when the pole wheel happens to move away from the equilibrium position, currents are induced in the rotor which according to Lenz's law tend to maintain constant the flux linkage of the pole-wheel. If the pole-wheel winding has no resistance, the induced current will remain unchanged and the pole-wheel voltage will be a one-valued function of the pole-wheel angle. The machine will therefore regulate itself without artificial stabilization ; this is known as the " auto-stabilization " of the ideal machine. Therefore we are able to state that, for artificial stabilization, the simple angle-controlled regulation (without a slip-controlled component) will be sufficient in all cases in which an ideal machine without rotor resistance would be inherently stable as a result of self-stabilization.

This self-stabilization tendency exists naturally also in real machines with a rotor resistance. If the excitation voltage is not regulated, then the self-compensation tendency of the generator will be ineffective owing to the decay of the currents initially induced. If, however, the voltage of the pole-wheel winding is increased as a function of ϑ by a value at least equal to that corresponding to the induced current of the pole-wheel, then this voltage will not decay but will be maintained as in the case of the ideal machine. This also explains why the time-constant of the machine has no effect on the stability conditions in case β.

In principle the conditions in case γ are entirely different, and even an ideal machine without resistance will not be stable in this case. It will not be sufficient merely to assist the machine in its self-compensating tendency, and therefore slip-controlled regulation will also be required.

A brief outline will now be given of another way in which this problem can be considered. When a non-regulated machine performs very slow oscillations about its equilibrium position, the rotor current and therefore the pole-wheel voltage remain constant. In the case

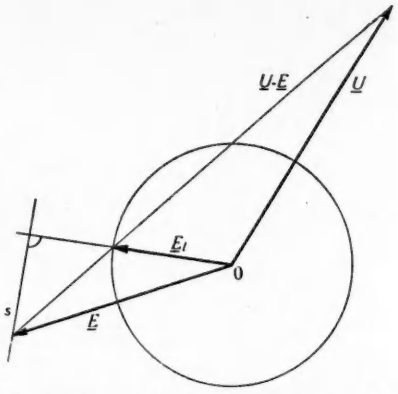


Fig. 5. **Definition of the air-gap voltage E_l of a synchronous machine.**

of very rapid vibrations, the conditions are different, the induced currents of the rotor hardly have the time to decay, and the vector **E** moves over a small portion of a curve of the type shown in Fig. 4. The terminal voltage **U**, the pole-wheel voltage **E** and the tangent *s* to the curve described by the vector **E** are shown in Fig. 5. The vector **E** — **U** is equal to the voltage drop across the synchronous resistance. If we now draw the perpendicular to *s* through the origin 0, and then draw a circle around 0 which will pass through the intersection of **E** — **U** with this perpendicular, then its tangent at the point of intersection with **E** — **U** will be parallel to *s*. Therefore when **E** moves backwards and forwards over a small portion of *s*, there will be a point on **E** — **U** which will move over a small distance on a circle around the origin. All this seems to indicate that in the case of small rapid vibrations of the synchronous machine there is a constant voltage $\mathbf{E}_l$ situated between **E** and **U**. This is known as the air-gap voltage $\mathbf{E}_l$ and the angle between $\mathbf{E}_l$ and **U** is denoted by ϑ_l. The conditions are complicated in the synchronous machine because the reactions to pole-wheel displacements are different on the two axes. The variations of the pole-wheel voltage and the air-gap voltage are not equal, hence the air-gap voltage should not be thought of as being rigidly connected to the pole-wheel. For many approximate calculations of dynamic stability it will not be possible to avoid working occasionally with the aid of assumptions which should not be regarded as entirely correct in the light of this theory[11].

If the construction of Fig. 5 is applied to a machine working under conditions corresponding to the stability limit of the ideal machine with a zero resistance, then it will be seen that in this case the air-gap voltage is actually perpendicular to the terminal voltage **U**. It can therefore be said that artificial stabilization by means of angle-controlled regulation alone is effective as long as $\vartheta_l < 90$ deg.

Regarding series excitation, it may be said that a series-excited machine behaves in principle in the

TABLE I.

Case	Pole-wheel angle ϑ	Non-regulated machine with rotor	Non-regulated machine without* resistance	Angle ϑ_l	Regulation required for stable operation
α	$\vartheta < 90°$	stable	stable	$\vartheta_l < 90°$	none
β	$90° < \vartheta < \vartheta_K$	unstable	stable	$\vartheta_l < 90°$	angle-controlled
γ	$\vartheta_K < \vartheta < 180°$	unstable	unstable	$\vartheta_l > 90°$	slip- and angle-controlled

* Also achievable in principle by means of series excitation.

same way as an ideal generator[12] without rotor resistance. Therefore it will be possible to stabilize a machine with the aid of series excitation in all cases where artificial stabilization can be achieved by means of a simple angle-controlled regulation alone.

The relationships of the three cases are summed up in Table I.

(To be continued.)

BIBLIOGRAPHY.

1. WANGER, W., and W. FREY: The problem of stability in three-phase power transmission over long distances. *Brown Boveri Mitt.*, 1941, *p.* 265.

2. FREY, W.: Investigation of the principle of an optimum economic voltage for power transmission over long distances. *Brown Boveri Mitt.*, Nov., 1946, *p.* 354.

3. FREY, W., and C. LAVANCHY: Stability of large asynchronous generators for power transmission over long distances. *Brown Boveri Mitt.*, Nov., 1946, *p.* 321.

4. NICKELE and LAWTON: Artificial stabilization of synchronous machines. *A.I.E.E.*, 1926, *p.* 864.

5. TIMOSCHEFF: Stability of electrical three-phase power transmission.

6. DARRIEUS: *Bull. S.E.V.*, 1942, *p.* 247.

7. FREY, W.: *C.I.G.R.E.*, 1946, Report No. 317.

8. *B.B.C. Mitt.*, 1941, *p.* 264.

9. FREY, W.: Application of the Nyquist criterion for stability. *Brown Boveri Mitt*, 1946, *p.* 59.

10. TOLLE: *Die Regelung der Kraftmaschinen.* 1909.

11. WANGER, W.: *Brown Boveri Mitt*, 1937, *p.* 99.

12. DARRIEUS: *C.I.G.R.E.*, 1946 ,Report No. 110.

U. S. A.

Determining Surface Roughness

By W. MIKELSON. (From *Mechanical Engineering*, Vol. 69, No. 5, May, 1947, pp. 391–393, 3 illustrations).

How to select, specify, and obtain desired surface finishes for machine-tool work is a far more difficult problem than is generally realized. What kind of a surface can be expected on a finished product when the specifications on the drawing simply say grind ? Experience shows that the roughness of resulting finishes, that is, the average depth of surface irregularities, may vary almost 10 to 1. What kind of a surface can be expected when the specifications contain complicated instructions covering the type of machine tool to be used, grit size, speed of operation, and so on ? Experience shows that the resulting finishes may vary as much as 4 to 1. On the other hand, where the specifications identify the finish by a symbol, referring to a sample block, much closer control is possible ; variation seldom exceeds 2 to 1.

PRACTICAL METHOD DEVELOPED FOR GAUGING ROUGHNESS.

Various instruments such as the profilometer and the surface analyser are available to measure surface roughness. Comparator microscopes permit detailed observation and comparison of surfaces, but do not actually measure roughness. These and other instruments are valuable for many purposes, but we have found they are not practical for general use in manufacturing operations where determination of surface roughness must be made quickly at frequent intervals. What is needed is a convenient method by which (1) the design engineer can select and specify the degree of roughness required, (2) the machine-tool operator can compare the result of his work with the specification, and (3) the inspector can check the finished product when the machining has been completed.

About 15 years ago, the author's company* first tried to develop a simple and practical method of specifying and checking surface roughness. The method adopted in the beginning involved the use of sample specimens of the actual work. These were first approved by the design group and then distributed in the shop. Where a product consisted of a number of parts, or where a shop produced a variety of products, the quantity of sample specimens needed was inconveniently large. As changes were made in design and new products added to the list of established products, the stock specimens became extremely unwieldy.

In an endeavour to reduce the stock samples and to simplify the procedure generally, a standard set of representative samples was prepared, depicting typical finishes arranged in orderly steps of roughness. Under this plan, which has now come into widespread use, the first step is for the design engineer to select from his set of specimens the proper finish for each piece of work. This finish is then specified by symbol on the drawing. The production department interprets the finish required with the aid of a duplicate set of samples. Finally, the inspector checks the work by comparison with a third set. In this procedure all comparisons are made simply by sight-and-feel methods. The use of

* General Electric Company, Schenectady, N.Y.

ROUGHNESS VALUES OF STANDARD SPECIMENS.

Symbol	General Electric symbol	Roughness, microinches: Average[a]	Roughness, microinches: Average peak-to-valley[b]	Typical methods of producing. (There are additional methods not listed here).
A	f^1	4	15	Ground, lapped, honed, microhoned, superfinished, etc.
B	f^2	8	28	Ground, lapped, honed, microhoned, superfinished, moulded, drawn, etc.
C	f^3	16	56	Ground, lapped, honed, reamed, scraped, superfinished, bored, burnished, planished, milled, moulded, precision-cast, cold-pressed, drawn, extruded, etc.
D	$f^{3\,1}/_2$	32	118	Ground, broached, reamed, scraped, turned, bored, burnished, milled, planished, moulded, precision-cast, cold-pressed, drawn, extruded, etc.
E	f^4	63	220	Ground, broached, rolled, shaped, turned, bored, milled, abrasive cutoff, reamed, moulded, precision-cast, extruded, drawn, etc.
F	f^5	125	455	Ground, broached, rolled, reamed, shaped, turned, bored, milled, drilled, spot-faced, counterbored, filed, punched, abrasive cutoff, moulded, precision-cast, extruded, forged, etc.
G	f^6	250	875	Ground, rolled, shaped, turned, bored, milled, drilled, spot-faced, counterbored, filed, punched, sand-cast, forged, precision-cast, etc.
H	$f^{6\,1}/_2$	500	1750	Ground, gas-cut, chipped, shaped, turned, bored, milled, sawed, filed, punched, sand-cast, forged, etc.
J	f^7	1000	3500	Ground, gas-cut, chipped, shaped, turned, bored, milled, sawed. sheared, nibbled, welded. punched, sand-cast, forged, etc.
K	f^8	2000	7000	Gas-cut, chipped, shaped, turned, milled, sawed, sheared, nibbled, welded, parting cut, sand-cast, etc.

[a] Determined by a profilometer or calculated.

[b] Determined by a surface analyser, a profile recorder, or calculated.

measuring instruments has been found to be necessary only in exceptional cases.

The design engineer specifies only the degree of roughness required and not the method by which it is to be obtained. This is done because it is felt that ordinarily the production engineer, familiar with the factory work loads and the equipment available, is in a better position to select the quickest and cheapest method of processing this product.

To cover the full range of roughness attainable with present-day machining and other methods, a set of specimens must include samples varying in degree of roughness from a smooth lapped, honed, or ground surface, to a rough-milled shaped, sawed, or gas-cut surface. The set must also be divided into intermediate steps frequent enough to permit the selection of a satisfactory roughness and not so frequent as to surpass personal ability to distinguish between adjacent degrees of roughness by sight and feel.

ABILITY TO JUDGE ROUGHNESS

Tests conducted within the author's company of the ability of reasonably experienced inspectors and production men, have indicated that 4 microinches average is the limit below which roughness cannot be judged satisfactorily. Visual and tactual selections made on various degrees of roughness below this point become confused and inconsistent. There seems to be no upper limit of roughness where a similar limitation applies. These investigations have also led to the conclusion that specimens above 4 microinches which vary in two-to-one steps of roughness can be quite consistently distinguished, provided that they are specimens made by the same or similar methods of machining.

Since surfaces processed by different methods have different appearances, even though the depth of the irregularities may be the same, it is considered necessary, particularly for the intermediate and rougher finishes, to provide several samples of each specific degree of roughness to indicate the differences in appearance and feel which might normally be encountered, using typical methods of processing. For the rougher finishes, the maximum number of samples required to represent any single degree of roughness seldom exceeds four. For the finer finishes, one or two is sufficient.

SAMPLE ROUGHNESS SPECIMENS.

The set of sample specimens developed by the company consists of ten metal blocks, each $2 \times 2^1/_2$ in., fitted into a box for protection and convenient handling. Each block is identified by a letter and represents a certain degree of roughness. An accompanying table shows the roughness value of each block as measured by a profilometer and by a surface analyser. Several of the blocks are subdivided into two or four different surfaces to show finishes of the same degree of roughness, but made by different types of machines. Any of the sample blocks can be removed from the box easily and held close alongside a machined surface for comparison of the degree of roughness.

PRODUCING ROUGHNESS SAMPLES BY ELECTROPLATING.

Before the war the company produced specimens for its own use by machining each block individually. This was an expensive and time-consuming process. With the advent of the National Defense program the need for sets of specimens was greatly augmented. A request by Army Ordnance for a large number of sets could not be filled because the company's precision equipment was busy on other work and personnel was not available to machine individually each of the thousands of specimens needed.

This request, however, prompted the company to explore means of reproducing specimens from an accurately machined master plate. Various methods and materials for producing replicas were suggested and tried, and a lengthy investigation was made in the company's laboratory to study accuracy of reproduction, uniformity of appearance, and cost. These investigations led finally to the selection of an electroplating method. Our experiments, later confirmed by others, indicated that the accuracy of reproduction possible was within 2 or 3 per cent, which is better than the accuracy of commercially available instruments for measuring surface roughness.

The electroplate process we use in manufacturing is similar to that used in the printing industry. A thin lead plate is pressed into the master surface to produce a negative impression on the lead plate. It is then pulled away from the master and a thin coat of nickel (0·003 to 0·005 in.) is electrodeposited on the lead impression. A coat of copper (0·010 to 0·015 in.) is next electrodeposited over the nickel to provide backing. The combined coats of plating are pulled loose from the lead, yielding a positive imprint of the original master on the surface of the nickel. This sheet of nickel and copper plating is then backed with additional material for rigidity.

MASTER PLATE CHECKED CAREFULLY.

Several makes of instruments are used as independent checks of roughness during preparation of the master plate. Smooth samples are measured both by the profilometer and the surface analyser. Where the range of these instruments is exceeded on the rougher specimens, a profile curve is plotted by a General Electric profile recorder, and the average roughness value of the profile calculated by dividing the peak-to-valley height by a factor of 3·5. Studies of this ratio seem to indicate that for smooth surfaces the ratio may be considerably higher, but for rough surfaces where the profile is relatively simple, the factor of 3·5 is approximately correct.

Although the tolerance permitted in the preparation of the master is very small and reproductions are faithful to $\pm$ 2 or 3 per cent of the master, the guaranteed accuracy is — 25, + 10 per cent of the nominal designated value. Most of this is safety factor to account for such items as point-to-point variations on the surface, uncertainties in commercial instruments used here and which may be used by others to check these specimens. Most commercial instruments of any one type can be depended upon to agree with each other within an accuracy of $\pm$ 15 per cent. Under careful experienced operation and with frequent standardization of calibration these same instruments will vary between $\pm$ 5 and 10 per cent.

SUPPLEMENTARY SPECIMENS SOMETIMES REQUIRED.

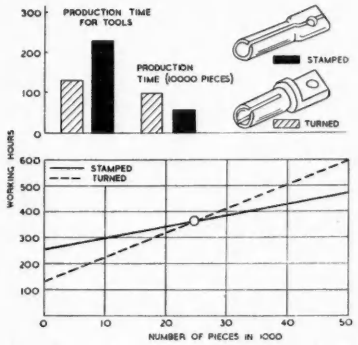
Supplementary specimens have from time to time been requested by certain groups within the company. These have included cylindrical specimens, flame-cut and sandblasted specimens. Samples are made and used for a short while but the trend in most cases seemed to drift back to the original flat set. Supplementary specimens, when made, are prepared and checked to correspond to the degrees of roughness provided in the standard set and the same method of specification and procedure of selection is used.

Use of the standard roughness specimens was tremendously accelerated by the war. They were widely employed in the aircraft, automotive, and electrical industries, as well as by Army Ordnance. The author's company furnished sets for a substantial part of the hundreds of subcontractors working with the company. Results cannot be exactly evaluated in dollars and cents, but there is no question but that their use contributed greatly to obtaining interchangeable and uniform surface finishes at minimum expense.

The Influence of Production on the Design of Components in Light Engineering

By. W. BAUERSACHS and P. GABLER. (From *Die Technik*, Vol. 1, No. 2, August, 1946, pp. 81–85, 25 illustrations.)

ONE important assumption for rational production is that design must be adapted to the production process to be used, as well as to decide upon the process which is most practicable. The best way to do this is to compare the expenditure necessary for alternative processes which can be employed. An example is illustrated by Figs. 1 and 2 which show a comparison of two processes which could be used to make a plug pin and which are either by press tools or by lathe tools. The comparison is confined to expenditure on wages and tools. For pressing the component, as designed for turning, is essentially redesigned, and the example shows that this can be done without impairing its technical expediency.



Figs. 1 and 2. **Comparison of expenditure for wages and tools used to manufacture plug pins.**

The wage reduction in the case of the pressed pin is offset by a greater expenditure on tools, but the curves of total production cost plotted against the number of components, crosses at the position for 23,000 pieces, and, therefore, above this figure the pressing process is definitely superior. It is assumed that comparatively simple press tools are used, but if high duty tools were used the saving in work and wages would be still greater. A consideration of this kind shows the great importance of assessing the probable number of pieces to be made when choosing the most suitable process, but to make a correct choice, the capacity of the tool used must be known.

To build up a rational production in light engineering, it is necessary to be familiar with new developments and to know the demands made by them on the design of components.

Impact Extrusion.

Impact extruding has recently been introduced into production in light engineering and found useful for the manufacture of hollow metal components. The possibility to deform, to some extent, the bottom of a hollow body allows to press out lugs for securing brackets, knobs, etc. This eliminates the separate production and attachment of special parts. For example, on a relay cover, the lugs for holding a wire handle shown in Fig. 3a and are produced by the extrusion of the cover, and the holes to take the wire handle were made by pressing in the needles which are shown in Fig. 3b.

If the tool is suitably constructed it is possible to manufacture hollow bodies with a partition in the centre, and articles as shown in Figs. 4 and 5 can be designed for extrusion in one operation, whereas if they were drawn, two cuplike parts would have to be joined together.

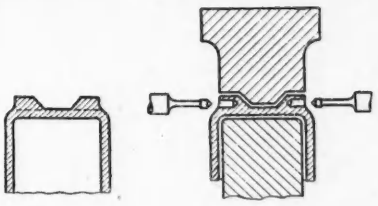


Fig. 3. **Impact extrusion design for a relay cover. The loops for fastening a wire handle are pressed in during the extruding operation.**

" Pins " can also be extruded to either side of a partition and this is also shown in these two figures.

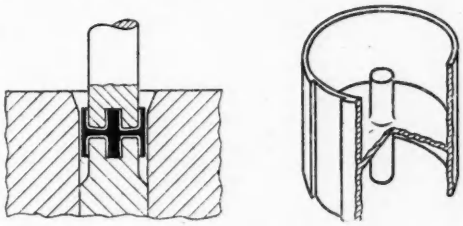
Die Casting.

Fig. 7 shows one example of economy by die casting when parts are properly designed. Components leave the dies after being formed and the accuracy of their dimensions is so high that no subsequent machining for assembly purposes is required. The process thus allows for the production of groups of components which can be joined in one assembly as, for example, in the die cast mounting block for a teleprinter shown in Fig. 7. The slots for the selector strips are cast-in simultaneously, and there are only seven die-cast components shown in Fig. 7 against the 63 necessary for the same purpose when made by other methods (Fig. 6.)

A further advantage of die casting is the possibility of casting-in, or inserting, components, and if the designer makes proper use of this the properties of the material of components are not only better adapted to their technical purpose, but one part can also be made of several different materials.

The armature bracket shown in Fig. 8 is an example showing how both advantages can be combined; the hardened recording blade, the armature of special material having magnetic properties, and the spring forming the hinge, are all three inserted and die-cast together. The result is: components mainly consisting of light metal, for reasons of weight, which incorporate the best material properties at all its working points. Screws, otherwise required for joining, are saved whilst the necessity for holes and threads, with the preparation of the mating surfaces which these require, are largely obviated.

Plastic inserts in die-castings are also possible, and these are particular advantages if the electrical insulating properties of these materials are utilized. The inserts are therefore not only combined mechanically, but may be simultaneously insulated from each other electrically. The designer must take care when parts are inserted in the mould that they are correctly located and firmly



Figs. 4 and 5. **Extruding in two directions in one operation.**

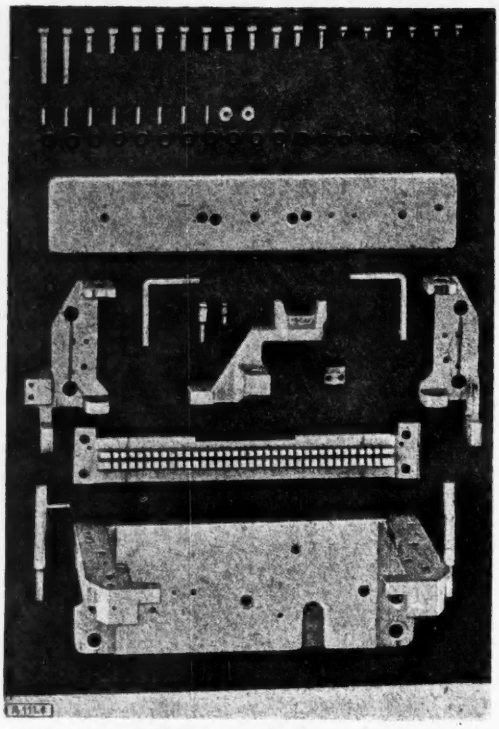


Fig. 6. **Assembly block for a teleprinter. Made up of 63 separate parts.**

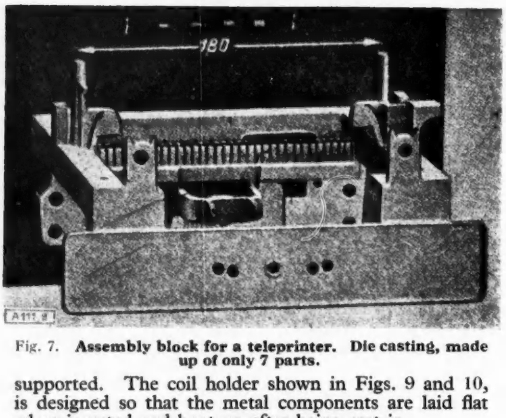


Fig. 7. **Assembly block for a teleprinter. Die casting, made up of only 7 parts.**

supported. The coil holder shown in Figs. 9 and 10, is designed so that the metal components are laid flat when inserted and bent up after being cast in.

Fig. 11 shows a bearing screw for a measuring instrument. The insert process is used to obtain electric insulation for the copper beryllium pin which is cast in with an Igamid jacket. The elastic properties of this synthetic material secure at the same time the screw in the housing and its snug fit is improved by slightly enlarging the core of the last thread. This problem would be difficult by other processes of thread production, but in this particular case it was easily possible by removing the top of the thread in the mould. If the screw were made entirely of copper-beryllium a larger amount of this metal would be used and the thread cutting process would be difficult whilst special

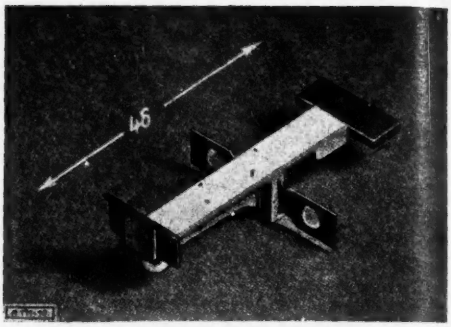
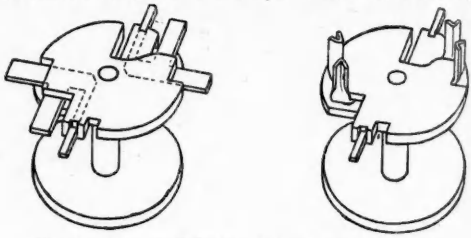


Fig. 8. **Armature bracket with inserted steel parts.**

means for insulating and securing the screw would have to be included in the design.

Welding instead of Soldering.

Welded joints are often superior to soldered joints for electric wiring installations. However, parts design must be made suitable for welding, and this may mean an alteration in shape such as shown in Figs. 12 and 13. The fundamental difference is that, for soldering, the material making the joint must be supplied separately but when an arc hand welding apparatus is used the material is partly from the loop and partly from the wire welded to it. The fact that materials become brittle and possess a " cast " structure due to smelting after welding must be taken into account and the weld must not be subjected to bending stresses. Also care should be taken that the weld is easily accessible to hand equipment. Such considerations have led to a change in the design for welded loops, and the basis on which the designs were adapted for welding is shown in Figs. 12 and 13. From these illustrations it can clearly be seen how welded joints can be unloaded either by



Figs. 9 and 10. **Coil holders with inserted connectors.**

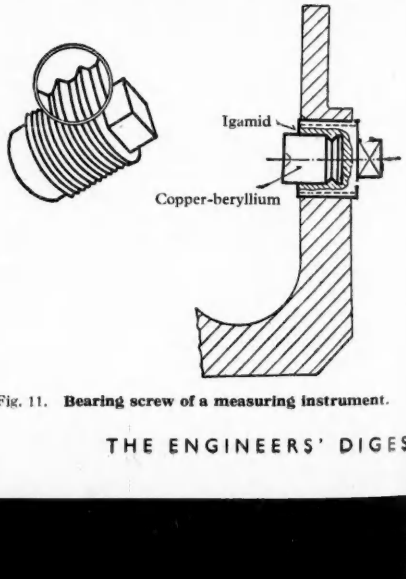
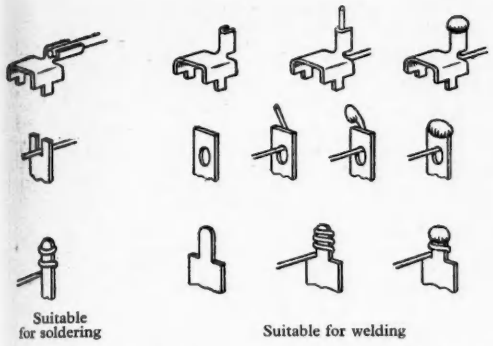


Fig. 11. **Bearing screw of a measuring instrument.**



Figs. 12 and 13. **Design of components suitable for soldering and welding.**

clamping the wire or by leading it through eye holes, or, by winding it round lugs, which are made extra long to provide the metal necessary for making the welded joint.

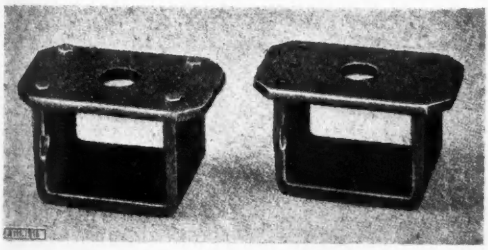


Fig. 14. **Conversion of a screwed junction method** (left) **to a projection welding job** (right). **6 projections are welded simultaneously.**

A further development of spot welding, known as projection welding, has proved satisfactory. The advantage is that several welds can be made simultaneously whilst the contact of the components to be joined is accurately determined by projections which are pressed out, even in the case of relatively rigid components, so that flawless welds are possible. This means that even very rigid components which have previously been bolted or riveted together can now be welded. Fig. 14 shows an example of this. Instead of four holes to take the screws of the pole plate, six projections are pressed out and welding occurs under a welding press at the positions of the projections.

Fig. 15 shows that sheet metal laminæ can be joined by resistance welding instead of by screws or rivets, and for this wires are welded—by resistance—across the lamellæ. This can be done quickly with simple equipment, and is sufficient to hold the lamellæ together when carrying out other operations, such as the face grinding of pole surfaces.

Using Interference Fits.

Since the forces which can be transmitted by interference fits, and the compressive pressure, which depends upon the dimensions between the components thus joined together, are known, this process has been widely used for production in light engineering works. For economy and accuracy alone it can be recommended, as a joining process, but another advantage is that components, difficult to manufacture can now be made from separate simple parts accurately and economically joined together after machining.

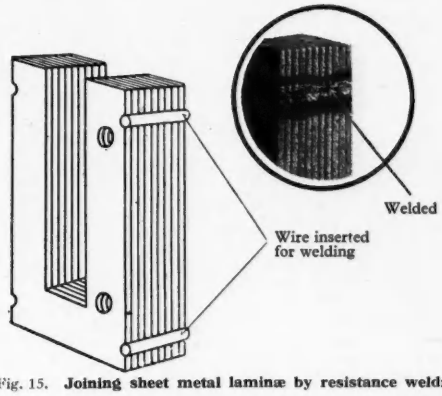


Fig. 15. **Joining sheet metal laminæ by resistance welding.**

The gear wheel shown in Fig. 16 was originally made in one piece with its hub. By making the hub separately and joining it to the wheel by an interference fit, after the teeth were cut, much time and material was saved, and tooth cutting time was reduced by 95 per cent. The teeth of a number of wheels could for this reason be cut in one process instead of dealing with each wheel separately.

Brazing.

Strong joints are made by brazing in a gas furnace, and this fact has opened up new possibilities for the design of components because separately finished parts can be joined together. By this means complicated components can be built up with economy of material and working time. Such combinations of parts have the features of a single piece which can be completely leak-proof at the joints. See Fig. 17. Components can be held together in the furnace by interference fits or by rivets until the final binding or joining is done by blowing copper into the joints. Due to the reducing atmosphere in the furnace components come out with clean surfaces and pickling or sand-blasting is therefore unnecessary even when surfaces are to be subsequently galvanized. For the designer who understands how to use this process, a great number of economical possibilities open up, because both pressed and machined parts can be joined together by it.

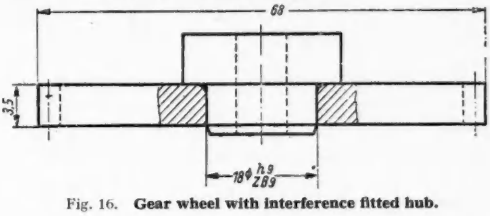


Fig. 16. **Gear wheel with interference fitted hub.**

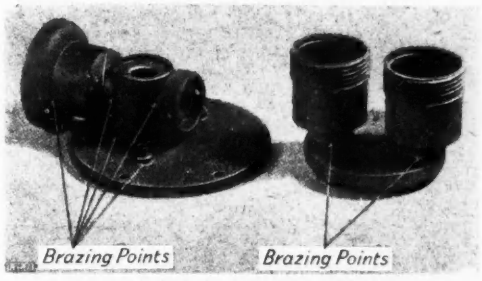


Fig. 17. **Designing components for brazing.**

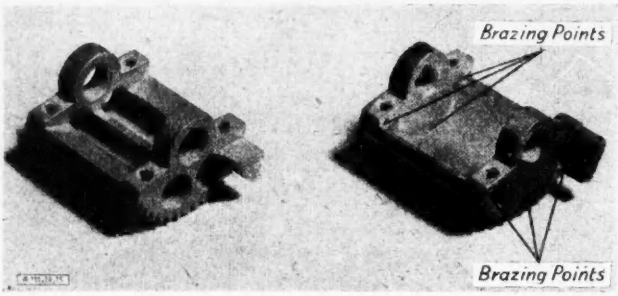


Fig. 18. **Manufacture of a switch segment.**

Left : switch segment, manufactured by machining profiled material. *Right :* component built-up of pressed metal parts brazed together resulting in a saving of 50 per cent in wages and material.

A typical example is a gear switch segment manufactured from three pressed parts brazed together as shown in Fig. 18. This shows the advantages of the process compared with the former method of manufacture, by machining from a piece of previously profiled material. The reduction of mass necessary for the correct operation of the component, which previously had to be lightened by drilling, is obtained automatically by the assembly of the light pressed metal parts. That the process is economical is clear because wages and material can be reduced by about 50 per cent.

Looking Ahead.

As well as the effect on design of the modern processes referred to, which are already widely used, other new developments will also greatly influence component design. These include the pressing and sintering of metal powders, which is already practised extensively in other branches of industry and will certainly extend to light engineering.

RUSSIA

Investigation of the Collection of Liquid Slag in an Experimental Furnace

By U. L. MARSHAK. (From *Izvestya Vsesoyuznoga Teplotechnicheskogo Instituta*, Vol. 16, No. 3, 1947, pp. 18-26, 8 illustrations.)

THE collection of liquid slag in a furnace chamber is based upon the retention of slag droplets either by the bath of liquid slag covering the bottom of the furnace or by the slag covered furnace walls. An investigation into the separation of liquid slag from the furnace gases was carried out with the employment of the model of an L-shaped combustion chamber as outlined in Fig. 1, this furnace being capable of burning 10 kg of powdered coal per hour. The pulverized product was taken from the cyclone of a mill and apportioned to the burner by means of a cellular rotary feeder (3), the feed rate being adjusted by varying the feeder speed within a range from 17 to 109 r.p.m. With a pulverized product of constant moisture content, and a fineness represented by 8 to 9 per cent residue on No. 70 screen,* the feed rate obtaining with this device proved sufficiently uniform.

Primary and secondary air were supplied by the fan (5) *via* separate electric air heaters (6) and (7), the primary air being heated to 500 deg. C. and the secondary

* Corresponding to No. 170 Tyler screen.—EDITOR, E.D.

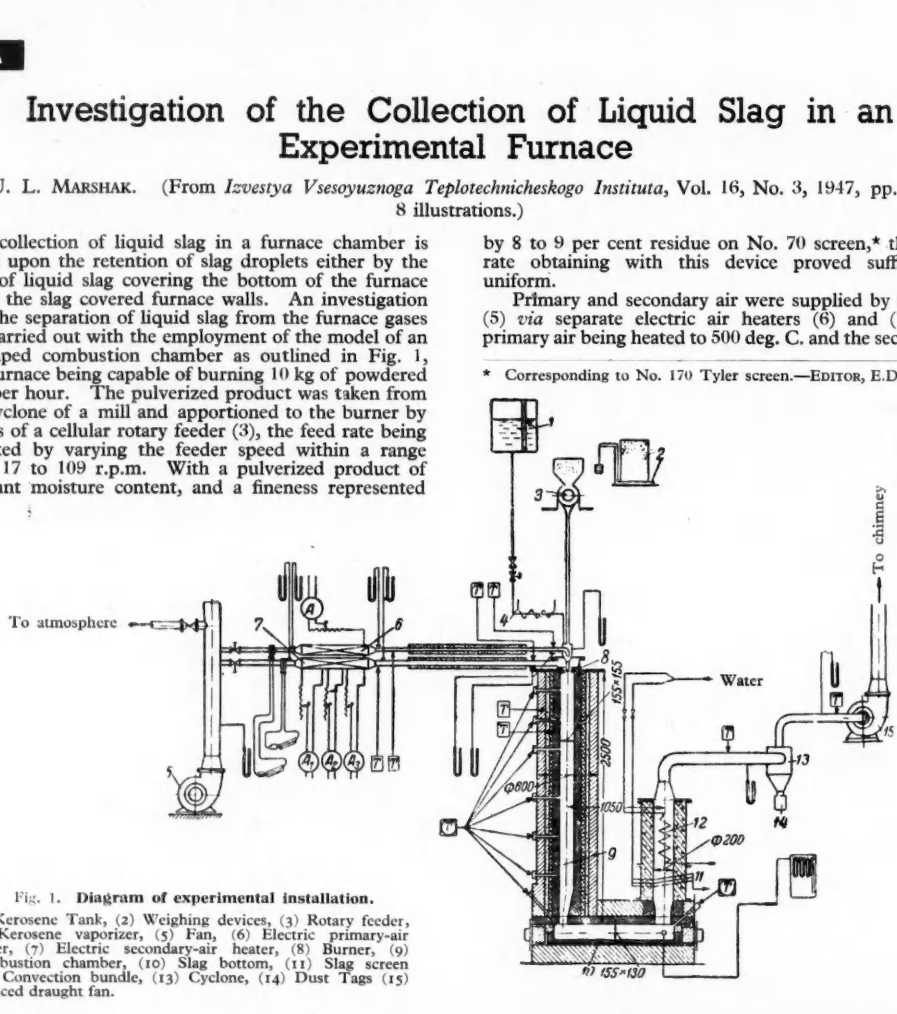


Fig. 1. **Diagram of experimental installation.**

(1) Kerosene Tank, (2) Weighing devices, (3) Rotary feeder, (4) Kerosene vaporizer, (5) Fan, (6) Electric primary-air heater, (7) Electric secondary-air heater, (8) Burner, (9) Combustion chamber, (10) Slag bottom, (11) Slag screen (12) Convection bundle, (13) Cyclone, (14) Dust Tags (15) Induced draught fan.

air to 600 deg. C. The burner (8) was of the injector type with tangential admission of the secondary air. The velocity of the primary air at the burner outlet was 10·1 to 11·2 metres per second. Lighting up was carried out by injecting kerosene vapour into the burner, vaporization being accomplished in the electric vaporizer (4).

The vertical part of the furnace was 155 × 155 mm in cross-section and 2·5 m high, while the horizontal part had a cross-section of 155 × 130 mm and was 1·05 m in length. The gases discharged from the vertical chamber at high velocity impinged upon the liquid slag which collected on the bottom of the horizontal chamber, the combined action of impact and change in direction of flow causing effective separation of the liquid slag droplets from the gas stream. Upon their discharge from the horizontal chamber the gases were passed through a slag screen (11) and a convection surface (12), the gas temperature at the outlet from the latter amounting to 300–450 deg. C. Finally, the flue gases were passed through the cyclone (13) of 200 mm diameter which collected any fly-ash still contained in the gases.

The time required for establishing temperature equilibrium in the furnace was from 6 to 8 hours during which time kerosene was fired exclusively, and the pulverized fuel firing test was begun only after full temperature equilibrium had been reached. Each pulverized fuel firing test lasted from 2 to 6 hours according to the ash content of the fuel. Prior to each test run the slag bottom (10) was filled to a height of 15–20 mm with slag derived from the same kind of fuel as that to be fired in the test. This slag became liquid during the aforementioned period of starting the furnace. During each test run the following readings were taken at 10 minute intervals :—Firing rate, temperature at entrance and exit ends of the slag bottom, furnace gas analysis, air flow and air temperature, flue gas and air pressures, and flue gas exit temperature.

The test results showed that in spite of the high rates of heat release employed, ranging from 900,000 to 1,250,000 cal. per cu.m. per hour, the loss due to carbon in ash amounted only to 0·2–0·4 per cent in the case of low volatile coal and to 0·5–0·77 per cent in the case of shale. This excellent result was chiefly due to the employment of high air preheat (from 400 to 580 deg. C.) and to the high furnace temperature prevailing. The latter approximated to 1600–1650 deg. C. in the case of the low volatile coal, and to 1340–1435 deg. C. when firing shale. Generally ignition took place immediately at the burner opening, and combustion was completed at the point where the flame reached the slag bottom. In the installation investigated the process of slag collection consisted of two successive stages, namely :—(*a*) the adherence of the slag particle to the walls of the vertical shaft, and (*b*) the collection of slag particles on the slag bottom. For this reason a distinction must be made between (1) the overall slag collecting efficiency $\eta = \frac{G_{coll}}{G_0}$ where G_0 is the total amount of ash introduced with the fuel into the furnace and G_{coll} is the amount of liquid slag retained, (2) the slag collecting efficiency η_m of the furnace, and (3) the slag collecting efficiency η_B of the slag bottom.

In Fig. 2 is shown the overall slag collecting efficiency η as a function of the velocity w_m'' with which the flame impinges upon the liquid slag level at the bottom. It will be noted that the collecting efficiency increases with rising flame velocity towards a limiting value. In the case of Chelyabinsk coal a maximum collecting efficiency of $\eta = 90$ per cent was obtained with a flame velocity of $w_m'' = 37$ m. per second; while in the case of the low volatile coal the optium of 88·5 per cent was registered with a flame velocity of 30 m. per second, and in the case of shale firing 97 per cent efficiency was reached with a velocity of 42·2 m. per second.

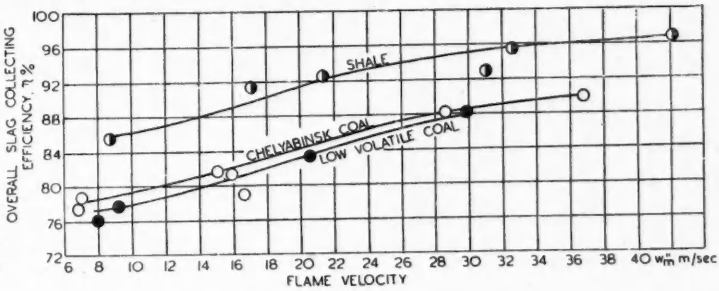


Fig. 2. **Overall slag collecting efficiency as a function of the velocity of flame impingement upon the slag bottom.**

The separation of the liquid slag droplets from the gas stream and their precipitation into the mass of liquid slag accumulating at the bottom of the horizontal duct was mainly due to centrifugal action created by the change in direction of the gas flow. This is proven by the graph reproduced in Fig. 3 which gives the relationship between the overall collecting efficiency and the Froude number, the latter being expressed by the ratio $w_m''^2/gh_g$, where h_g is the distance from the furnace throat to the slag level at the bottom.

With diminishing velocity of flame impingement upon the liquid slag level a gradual decrease in the amount of slag collected obtains owing to the diminished centrifugal effect. With very low flame velocities—approaching zero—the slag particles will preferably precipitate upon the walls of the furnace, that is to say, for $w_m'' = 0$ it will be $\eta = \eta_m$. The vertical walls of the furnace will also be covered with a thin layer of liquid slag and this part of the furnace will therefore act as a slag separator owing to the turbulent movement of the gases. Moreover, in the case of the experimental furnace much of the slag retaining effect of the furnace walls was due to the large *length/equivalent diameter* ratio of the furnace which in this instance was $L/D = 16$.

The collecting efficiency of the slag bottom can be expressed by

$$\eta_B = \frac{\mu''_m - \mu}{\mu''_m}$$

where $\mu_m'' = \mu_0 (1-\eta_m)$ is the ash concentration in the flue gases at the point where they come into contact with the slag at the bottom, $\mu = \mu_0 (1-\eta)$ is the ash concentration in the flue gases at the point where their contact with the slag bottom terminates, and μ_0 is the initial ash concentration in the flame. The expression for η_b can therefore also be written thus :

$$\eta_B = \frac{\eta - \eta_m}{1 - \mu_m}$$

It is this formula which has been used for establishing

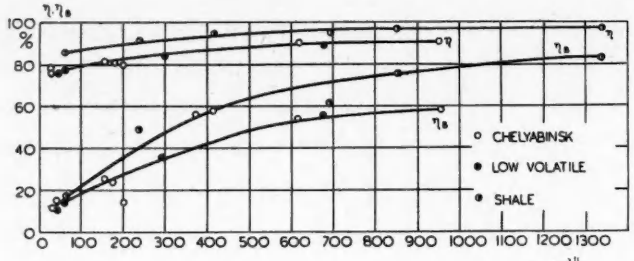


Fig. 3. **Overall slag collecting efficiency and slag bottom collecting efficiency as a function of the Froude number**

$$F = \frac{w_m''^2}{g\,h_g}$$

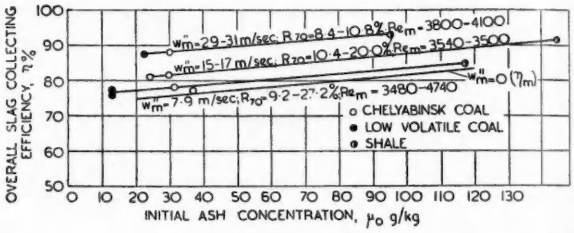


Fig. 4. **Overall slag collecting efficiency as a function of the initial ash concentration in the gases.**

the η_B characteristic as function of the Froude number as shown in Fig. 3. The influence of the initial ash concentration in the flame upon the effective slag collecting is charted in Fig. 4. The increasing effectiveness of the slag collecting process with rising initial ash concentration in the flame can be explained by the fact that the separation of very large slag droplets takes place very rapidly; but the subsequent separation of smaller fractions takes place much more slowly, so that a certain concentration remains in the leaving gases which is very difficult of separation. Thus, the larger the initial concentration of ash in the flame, the greater is the slag collecting efficiency.

An evaluation of the test results allows the establishment of certain fundamental principles governing the slag collecting efficiency of full-size furnaces.

(1) The retention of liquid slag on the walls of the combustion chamber is due to the mobility of the slag droplets under the influence of the turbulence of the flame. If turbulence is absent, then the remedy will lie in considerably increasing the length/diameter ratio of the furnace. Thus, a furnace may either be of the small combustion chamber type characterized by considerable height and small cross-section, or it may be of the type incorporating a throat as shown in Fig. 5a. According to Prof. Ramzin the theoretical relationship between the slag collecting efficiency η_m and the length/diameter ratio of the furnace can be expressed by:

$$\eta_m = 1 - e^{-\frac{4\omega}{w_g \gamma_g} \cdot \frac{L}{D}}$$

where ω is the mass velocity of the gases in kg./sq.m. per second,

w_g is the flame speed in m. per second,

γ_g is the weight of gas in kg./cu.m.

For a flame velocity of 7–8 m. per second the test results yielded $\omega = 0{\cdot}03$ kg./sq.m. per second for Chelyabinsk coal and $\omega = 0{\cdot}043$ kg./sq.m. per second for shale; and the relationship $\eta_m = f(L/D)$ therefore has the numerical values given below:

L/D:	2	4	6	8	10	12	14	16
η_m, %	17	30	41	51	59	66	72	76

Burners of the turbulent type are called for from the aspect of slag separation, since the centrifugal effect produced by the flame assists the deposition of slag upon the furnace walls.

(2) The retention of slag particles by the slag bottom will be the larger the greater the centrifugal effect produced by the change in the direction of flame travel. For this reason the flame velocity at the point where the flame approaches the slag bottom should be made as large as possible. On the other hand, the distance between furnace throat and liquid slag level should be as small as possible.

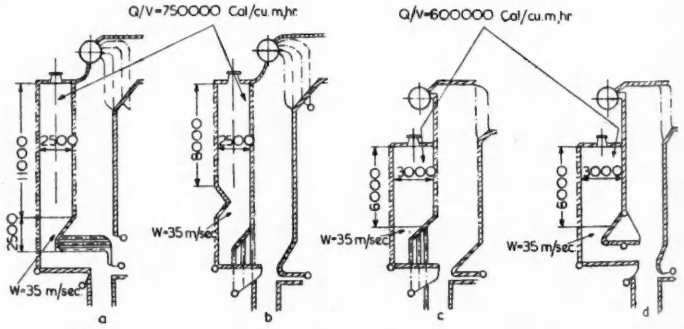


Fig. 5. **Furnaces for 20 ton/hour boiler ensuring maximum collection of liquid slag.**

These design principles were followed in the construction of the first full-size slag tap furnaces installed in Russia, and outlined in section in Fig. 5d. In the case of large boilers the separating effect can be increased by passing the gases through a refractory-covered screen subsequent to their sweeping over the slag bottom (Fig. 5c). In boiler furnace practice it will be advantageous to resort to a type of multi-stage slag separation as exemplified by Fig. 5b, which shows a furnace type incorporating the various principles of slag collection as enumerated above.

Influence of Structure and Composition on the Elastic Properties of Metallic Alloys

By L. GUILLET. (From *Le Génie Civil*, Vol. 124, No. 3, February 1, 1947, pp. 45–50, 17 illustrations.)

ELASTIC PROPERTIES.

YOUNG'S modulus of elasticity E and Coulomb's modulus of rigidity C can be measured by static or dynamic methods. If the loads are sufficiently small deformations can be assumed to be purely elastic and proportional to the loads. The two moduli then represent the ratio of load per unit cross-section to deformation per unit length and are characteristic properties of the material tested. For isotropic materials, they are connected by the equation

$$C = \frac{E}{2(1 + 1/m)} \quad \text{where } 1/m = \text{Poisson's ratio.}$$

This equation is not valid for anisotropic monocrystals nor for orientated (e.g. cold worked) poly-crystalline structures. However, the deformation is never strictly elastic and proportional to the load. Dissipation of energy in heat and internal strain leads to a mechanical hysteresis effect which, although not measurable in static tests, damps the oscillation amplitude in dynamic tests. The damping effect of internal friction is characterized by the decrement, i.e., the change of amplitude during one complete oscillation. In practice, the mean decrement is measured between the first and n–th oscillation and given by the equation

$$\delta_0^n = \frac{1}{n} \log_e \frac{\alpha_0}{\alpha_n}$$

Static and dynamic measurements of the moduli lead to slightly differing results. Static methods may be said to test the isothermic and dynamic methods the adiabatic moduli.

TEST APPARATUS.

The apparatus illustrated by Fig. 1 uses two identical coupled pendulums P_1 and P_2 consisting of leaf springs with attached weights suspended from plate A which forms the lower chuck for the test specimen E which is of 5·64 mm. diameter and 60 mm. length. Lever K frees plate A after the specimen has been inserted. The pendulum P_2 is held in its vertical equilibrium position whilst P_1 is allowed to swing from a starting position after lever l–m has been depressed and the stop watch C started. If P_2 is now freed and the specimen E is perfectly rigid, P_2 would remain stationary. Any flexibility of E, however, would cause the pendulums to swing like coupled pendulums, with mutually superimposed oscillations. At first, P_1 only would swing, P_2 be at rest. Then P_1 imparts energy to P_2 which begins to swing, increasing in amplitude as P_1 is damped, until finally P_2 only swings, P_1 is at rest. The energy exchange is then reversed, P_1 swings again, P_2 is damped. A small scale arranged next to the pendulum pointer P_2 indicates when precisely P_2 is at rest again, the stop watch is then stopped and the period from rest to rest of P_2 is measured. This period is the shorter the more flexible test specimen E is, and the modulus of flexibility A, related to Young's modulus E, is proportional to the time measured.

$$A = \frac{4\pi M l^3}{T^3} \times \frac{64}{d^4}$$

where M = pendulum mass, T = measured period, l = length, d = diameter of test specimen E. d appears to the 4th power and must therefore be obtained with the greatest precision (at least to within $^1/_{100}$ mm.). The damping capacity (internal friction) can be obtained either by measuring the decrement of maximum amplitudes of P_1 when P_2 is at rest, or by measuring the energy needed to maintain undamped oscillations. The decrement values however depend on oscillation amplitudes (Fig. 3) and frequencies. Some plastic atom or crystal re-arrangements can occur only at low frequencies (10 to 20 cycles/sec. as in the mechanical test described) but have no time to establish themselves at higher frequencies, 1,000 or 2,000 cycles/sec. as used in acoustic test methods. Results found at higher frequencies, however, are qualitatively comparable to those given here from low frequency tests.

Chevenard's micropendulum (Fig. 2) uses a test specimen 1·5 mm. diameter, 10 mm. long and avoids

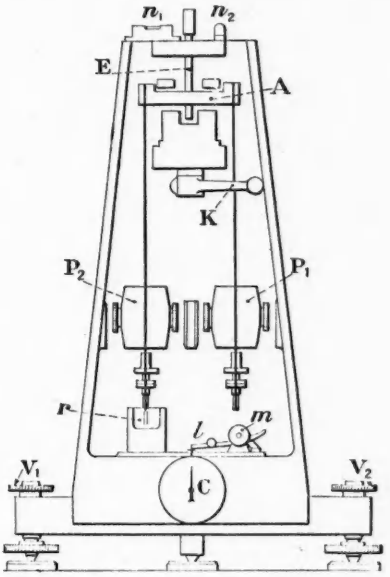


Fig. 1. **Test apparatus of Le Rolland-Sorin for the measurement of the elasticity modulus of metals.**

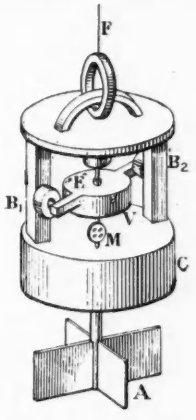


Fig. 2. **Chevenard's micro-pendulum for torsion tests.**

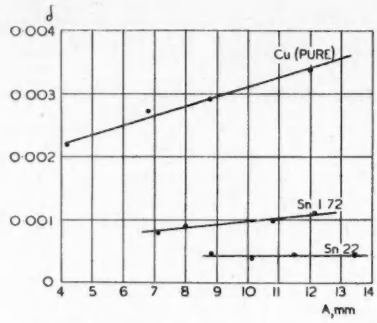


Fig. 3. **Change of decrement as a function of oscillation amplitude, for three different *Cu-Sn* alloys.**

any energy dissipation in the support by suspending the whole apparatus from a long torsionless steel wire *F*. A current is passed through the electro-magnets B_1 and B_2, the arms of disk *V* are attracted and disk *V* is deflected from its position of equilibrium through a torsion angle of 0 deg. 18′. If the modulus of rigidity of the test material is known, the maximum shear stress can be calculated (for *Cu*, stress is 1·16 kg/mm²). The oscillations are registered on light sensitive paper moved by a chronograph and the diagrams show directly the decrement of amplitudes. The modulus of rigidity is calculated from the frequency (15 cycles/sec. for *Cu*.). The mean decrement for every 100 cycles is obtained

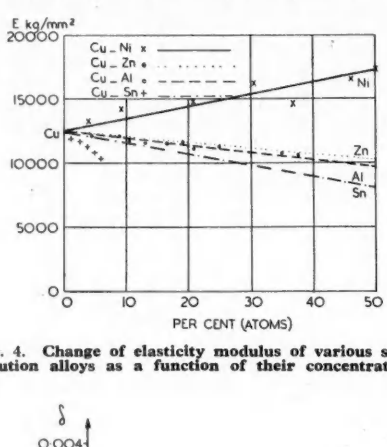


Fig. 4. **Change of elasticity modulus of various solid solution alloys as a function of their concentration.**

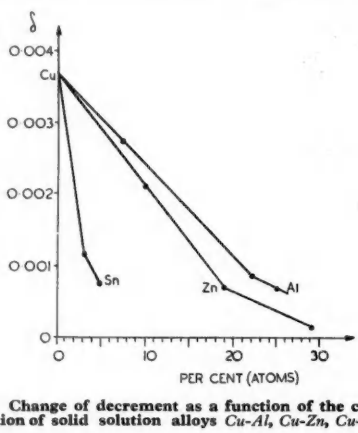


Fig. 5. **Change of decrement as a function of the concentration of solid solution alloys *Cu-Al, Cu-Zn, Cu-Sn*.**

from the formula given, and shown in Fig. 3 as a function of the amplitude of every 50th cycle. The straight lines of the graph are extrapolated to the initial amplitude of 14 mm., and the "initial decrement" δ has been used for the comparative results of this investigation. δ decreases with decreasing amplitudes but retains a finite value even for very small amplitudes, which is an indication of the remaining internal friction.

These two test methods have been specially adapted to the investigation of the relative influence of metallographic factors on the elastic constants of metals. Test pieces are small and can be cut from solid cast pieces if they cannot be worked. Small stresses permit the testing of very brittle materials. On the other hand, any crack, blow hole or surface irregularity influences results and test pieces must be machined with great care, polished, and annealed in vacuo.

PURE METALS.

For industrially pure metals, Young's modulus of elasticity varies from 1,600 kg/mm² for lead to 54,000 kg/mm² for iridium (See Table I), the corresponding modulus of rigidity varies from 600 kg/mm² for lead to 21,000 kg/mm² for iridium. The moduli are a periodic function of the atomic numbers of metals and, generally speaking, are high for metals of low atomic volume and high fusion temperature. More exact formulations of this relationship have been attempted but not yet been confirmed by tests. The internal friction is always very small and varies from $0{\cdot}46 \times 10^{-4}$ for aluminium to $54{\cdot}2 \times 10^{-4}$ for tin (see Table I).

TABLE I.

ELASTIC CONSTANTS OF INDUSTRIAL METALS.

	Young's modulus of elasticity *F* kg/mm²	Internal Friction (Decrement) $\times 10^{-4}$
Be	30000	—
Mg	4500	2·1
Al	7200	0·46
Si	11500	—
Mo	59000	5
W	41500	—
Fe	21500	20
Ni	22000	72·1
Co	20400	—
Mn	20200	—
Rh	38600	—
Ir	53800	—
Pt	17300	—
Cu	12500	35
Ag	8200	50
Au	8000	24
Zn	10000	7·7
Cd	6400	11
Sn	5500	54·2
Pb	1600	45·7
Sb	6400	—
Bi	3500	17·6

The decrement values are affected, however, by the presence of impurities. The modulus changes slightly with micrographic structure and diminishes with the amount of cold work done. The internal friction is more for poly-crystalline structures (grain boundary influence) than for mono-crystals, and also more for cold worked than for annealed structures. This effect is specially important if oscillation amplitudes are small. The grain size must therefore be kept constant for comparative measurements of decrements of different metals.

SOLID SOLUTIONS.

Metals and alloys solidify in differently orientated crystals of cubic, hexagonal, or trigonal structure. Several metals together may form solid solutions, i.e., when solidifying they form homogeneous structures from atoms of the constituent metals. These structures are normally stable at room temperature within certain ranges of concentration only. Thus Fig. 6 shows six ranges of one-phase solid solutions (α, β, γ, σ, ϵ, η) separated by other ranges where two phases are in

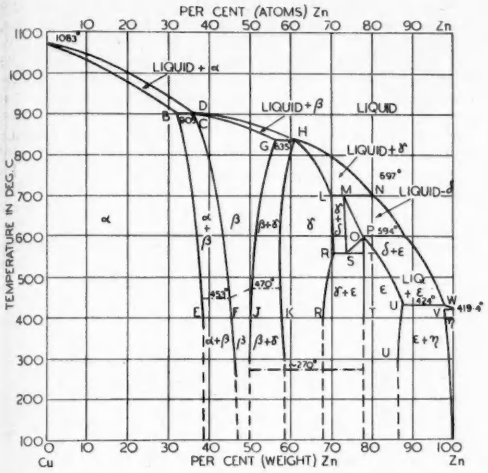


Fig. 6. **Equilibrium Diagram for *Cu-Zn* alloys (Hansen.)**

equilibrium. The crystal structures of these solid solutions are illustrated by Fig. 7. The extreme α and η solid solutions often show the same basic structure as the major constituent metals whilst the intermediate β, γ, ϵ solid solutions crystallize in systems very different from those of the constituent metals and show different mechanical properties. The γ phase is very brittle, is a poor heat and electricity conductor and is diamagnetic. The β and ϵ solutions are simpler and have metallic qualities, i.e., are relatively good conductors and hot forgeable. These structural differences recur in other alloys like *Ag–Zn* and *Au–Zn* in the same order. Their β, γ, and ϵ solutions show properties similar to those of *Cu–Zn* alloys. Apart from this important influence of the crystal structure on the general properties of alloys, the interatomic bond also determines metallic qualities. It is generally assumed that in metals some peripheral electrons are able to move freely between neighbouring atoms and thus carry an electric current between different potentials in the metal. The simple β structure supports electron mobility whilst the homopolar γ structure largely restricts it and is therefore not a good conductor of electricity.

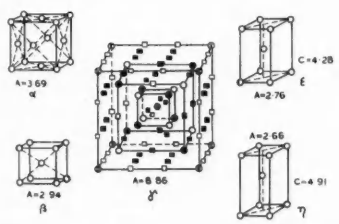


Fig. 7. **Crystalline lattice structures of different phases of *Cu-Zn* alloys.**

The influence of chemical composition on the elastic properties of alloys was first studied in the case of extreme solid solutions of *Cu–Ni*, *Ag–Au*, *Cu–Zn*, *Cu–Sn*, *Cu–Al* and others. The modulus varies linearly approximately in accordance with the lever rule (Fig. 4). If the constituent metals of the alloy have very unequal densities, then this law is only correct if the composition is given in volume per cent. The decrement diminishes rapidly at first, then less rapidly as the concentration of the minor constituent increases (Fig. 5), and it thus follows the behaviour of electric conductivity. Where solid solutions undergo a disorder-order change, i.e., a re-distribution of atoms from a disorderly into an orderly structure, it is accompanied by a slight increase of the modulus and a considerable increase of internal friction. If e.g. the substitutional solid solution *Au–Cu* is quenched in cold water from 650 deg. C., a disorderly face-centred cubic structure is obtained. If it is slowly cooled (30 deg. C. per hour) after 100 hours annealing at 380 deg. C., an orderly tetragonal structure appears with a logarithmic decrement 50 times larger than that of the quenched structure. Similar results were found for *Ag–Zn* alloys.

Intermediate solid solutions of uni-valent (*Cu*, *Ag*, *Au*) with di-valent (*Zn*, *Cd*) metals have been specially studied. Their γ-phase shows a high value of the elastic modulus, sometimes much higher than that of the constituent metals, whilst the damping capacity is very small. Analogous results have been obtained for alloys of uni-valent with tri-valent (*Cu–Al*) or tetra-valent (*Cu–Sn*) metals. The maximum modulus and minimum decrement values invariably occur for an electrode concentration (ratio of numbers of valency electrons to atoms) of 21/13, i.e., with compositions Cu_3Zn_8, Ag_5Zn_8, Cu_9Al_4, $Cu_{31}Sn_8$. (See Figs. 8 and 9). The γ-phases are very brittle, test pieces have to be taken from the as-cast state, X-rayed for faults and ground at very high speeds. The edge of the gigantic γ-crystal structure (Fig. 7) is 3 times longer than that of the body-centred cubic β-phase and should therefore contain $3^3 \times 2 = 54$ atoms, but

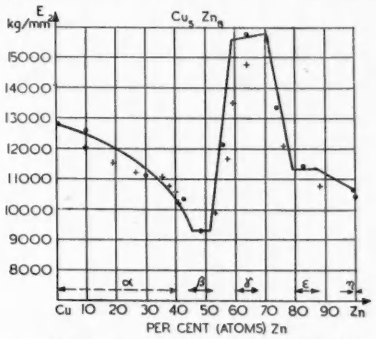


Fig. 8. **Change of elasticity modulus of *Cu-Zn* alloys as a function of concentration.**

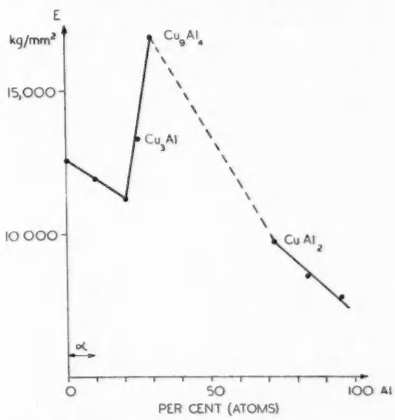


Fig. 9. **Change of elasticity modulus of *Cu-Al* alloys as a function of concentration.**

actually only contains 52 atoms (Bragg) as the centre and 8 corner atoms are suppressed. Thus the whole structure is slightly distorted, the closest-packed planes which usually offer the easiest slip directions are deformed and those plastic deformations which form the main part of internal friction at low frequencies are prevented. The bell-founder chooses a γ–bronze approaching, as far as brittleness allows, the $Cu_{31}\ Sn_8$–composition because the low value of internal friction determines the quality of the sound.

The face-centred or body-centred cubic β–phases have a simple metallic structure with improved damping qualities (possibility of easy slip). The elastic modulus does not deviate markedly from the values for the pure metals (Figs. 8 and 9) but the decrement of body-centred cubic β–phases always shows a maximum value for compositions of simple atomic concentration ratios like *CuZn* (Fig. 10) or Al_3Cu. These few examples show that the elasticity modulus is more sensitive to changes of the inter-atomic bond whilst the internal friction depends more on the crystalline structure.

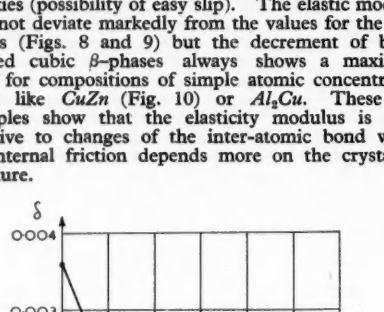


Fig. 10. **Change of decrement of *Cu-Zn* alloys as a function of concentration.**

TWO-PHASE AND MULTIPLE-PHASE ALLOYS.

Alloys consisting of two conjugate solutions, when heated above a certain temperature, normally form one-phase solutions. By a rapid quench these one-phase solutions may be preserved in a supersaturated state even at room temperature. Thus, the *Cu–Sn* alloys of Fig. 11 have a eutectoid change point at 525 deg. C. One specimen was quenched in cold water from 650 deg. C., another one annealed for 2 hours at 650 deg. C. and slowly cooled at the rate of 4 to 5 deg. C. per min. It was then found that the modulus of elasticity was considerably reduced by quenching (Fig. 11) and had its minimum value for the quenched eutectoid alloy.

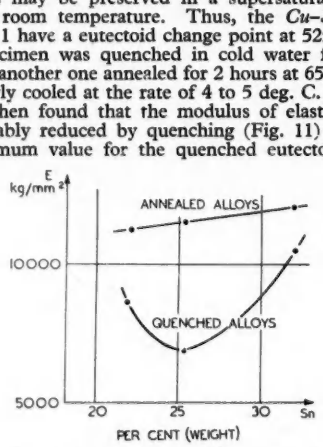


Fig. 11. **Influence of heat treatment on the elasticity modulus of *Cu-Sn* alloys.**

On tempering, the initial value was slowly restituted. Analogous results were obtained with *Cu–Al* alloys. This effect would explain why bronze bells of this composition give a deeper sound when chill cast. The phenomena preceding precipitation of one phase of a supersaturated solution do not seem to influence the modulus but they noticeably increase the damping capacity. On the whole, two-phase alloys and one-phase solid solutions are not very different in their influence on modulus and decrement.

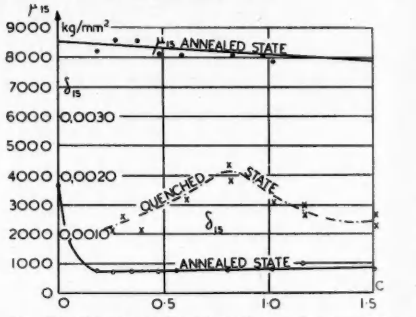


Fig. 12. **Elastic properties of steel as a function of the carbon content.**
μ = modulus of rigidity, δ = decrement.
(according to Chevenard.)

The modulus decreases slowly with a mounting carbon content in ordinary steels. The decrement however, falls rapidly first and remains stationary at a value of 5×10^{-4} for steels with 0·2 or more per cent carbon (Fig. 12). Quenching again slightly reduces the modulus but appreciably increases the decrement which reaches a maximum value for quenched eutectoid steel. Tempering then slowly restitutes the original decrement value for annealed steel. The damping capacity of heat treated steels is therefore smaller than that of normal steels. Graphite present in flake form in cast iron very much increases the damping capacity, and this is one reason for the modern tendency to use cast crankshafts. Cast machine frames are often preferred to fabricated ones because they damp out noise. Any two-dimensional discontinuity increases internal friction and the decrement value has often been used for the detection of internal flaws and incipient corrosion cracks.

CONCLUSIONS.

(1) The elastic modulus is an atomic property of metals and alloys and is only slightly affected by chemical composition or structure. It is hardly possible to modify appreciably the modulus of a metal by alloying if the alloy has to conserve its metallic character, and particularly its malleability. Only an intermediate modulus value, between those of the constituent metals can thus be obtained. Quenching, though it increases the elastic limit, does not affect the modulus. Higher stresses will therefore always lead to increased deflections. Only homopolar intermetallic alloys have a higher modulus, but these are non-metallic in character and usually very fragile.

(2) The damping capacity (internal friction) is very sensitive to changes in chemical composition and crystal structure, as is electric conductivity. Unlike the modulus the decrement is noticeably affected by impurities and even small alloying additions and also by cold working. Homopolar alloy compositions seem to possess the smallest damping capacities. Generally, any disturbance of the regularity of the crystalline lattice structure diminishes the damping capacity. One can therefore change the damping capacity by alloying, heat treatment, or cold work and thus avoid dangerous resonance vibration stresses.

Metal Stampings in Small Lots at Reasonable Fabrication Cost

By M. J. MIKULAK. (From *Product Engineering*, Vol. 18, No. 6, June, 1947, pp. 105-109, 9 illustrations.)

METAL stampings in small lots required the development of a process for producing a limited number of die-cut parts without prohibitive die cost. Although temporary or push-through dies were known 25 years ago, only recently has their manufacture been undertaken on a production basis reducing costs to practical levels.

At first only simple blanking and piercing operations with liberal tolerance limits were considered, but subsequently forming operations were also included. With the new techniques developed during the last decade, no metal stamping is too intricate, and no tolerance limit too close for this small lot process.

DESIGN FUNDAMENTALS FOR STAMPINGS.

The fabrication of metal stampings in small lots closely parallels the production of the same parts by conventional stamping methods, but a few basic requirements should be met for economic production.

Dimensions on stampings often need not be held to closer tolerances than on castings ; but the tolerances on stampings usually are comparable with the limits specified on machining operations, and consequently, cost of production is increased with no gain in utility of the part. Where close tolerances are necessary, they can be held on stampings of good design. For greatest economy, ± 0·002 in. is the recommended tolerance on the size and distance between holes, although this limit can be held to ± 0·001 in. when necessary. On blank dimensions up to 3 in. a tolerance of ± 0·005 in. is a reasonable minimum, with an additional 0·005 in. for each additional 3 in. of length.

The size and location of the holes is often considerably more critical than the contour of the blank. Also piercing is more economical than drilling. In drilling there is practically no limit on the location of the hole with respect to the edge of the part ; whereas in piercing, holes should be located to allow a distance equal to the thickness of material between the edge of the hole and the edge of the part, to avoid a bulge on the periphery. On thin material the edge distance should be at least $\frac{1}{32}$ in. On thicker materials, of $\frac{1}{8}$ in. or more, which have greater rigidity, it can in some cases be less than the thickness of material.

When the holes in a metal stamping are used as bearing surfaces, requiring a smooth finish that is free from tool marks and fractures (particularly in the case of parts for instruments, clocks and light machines), the holes are usually drilled or pierced undersize and then reamed to size. If the hole is pierced, minute fractures are present on its entire perimeter, which will extend into the adjacent material in varying amounts, depending on the thickness. For this reason it is advisable to allow a little more stock for reaming to be sure these fractures are eliminated. The following table gives the recommended allowance for various thicknesses of sheet material :

Material thickness, in.	Pierce undersize, in.
0·032	0·005
0·062	0·008
0·125	0·015
0·187	0·022
0·250	0·028
0·312	0·032
0·375	0·050
0·500	0·062

When two parts are to be bolted, riveted or spot welded together, it is advisable to provide for this purpose a hole in one part and a dowel extrusion in the other, see Fig. 1 (A), which can be held to close tolerances, and will provide a simple means for accurately positioning the parts. Bolt or rivet holes would not be accurate enough because some clearance must be allowed on the holes to insert the fastening means.

A common application for metal stampings is slide plates in many different types of equipment. Usually two of these are mounted on a common base in which the alignment of the corresponding holes is critical. Most designers locate these holes from the formed side as shown in Fig. 1 (B). This is impractical and costly because it is difficult to hold this dimension to close tolerances. A more practical and accurate design, shown in Fig. 1 (C), consists of a substantial leg which rests on the base and from which all the holes can be located to close tolerances. The leg, or legs, should extend from 0·005 to 0·010 in. past the formed portions at X to make sure they will rest firmly on the base.

Frequently a hole must be positioned within a close tolerance to a formed side of a part, Fig. 2 (A). Since the thickness of the sheet varies, 0·004 in. being the recognized variation in 0·125 in. stock, the surface on the formed side of the part that will exclude the sheet thickness should be made the reference plane. If possible, the surface on the formed side nearer the hole should be chosen as the reference plane because dimension M is easier to hold than dimension P. To hold dimension P to close tolerances, the hole must be pierced after the side is formed, thereby causing extra tooling and fabrication expense.

Since the most economical process is to blank, pierce and then form, a hole should be far enough away from a formed portion so as not to be distorted by the forming operation. If the distance between the edge of the hole and the inside surface of the formed side is not less than $1\frac{1}{2}$ times the thickness of the material plus the inside forming radius, the hole can be pierced before forming, Fig. 2 (B). If the hole must be closer than this distance, it should be pierced after forming to avoid distortion. There are, of course, exceptions to this rule, depending on the type and thickness of the material and the radius of the forming punch.

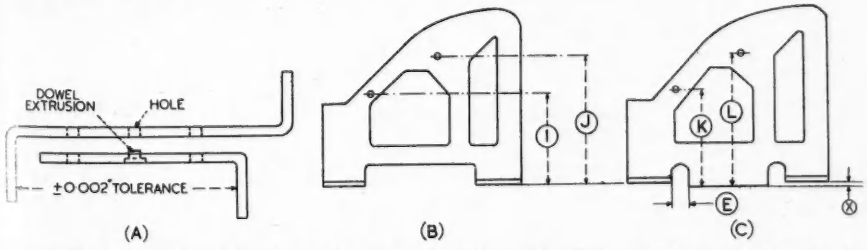


Fig. 1. **(A) Dowel extrusion can be useful in aligning parts ; (B) is less desirable than (C) in precise location of holes.**

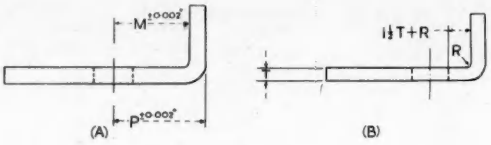


Fig. 2. **(A) Where precision in positioning is essential, holes can be referenced to that side of a formed portion to avoid variations in sheet thickness. (B) Minimum distance of holes from the formed portion for economy in stamping.**

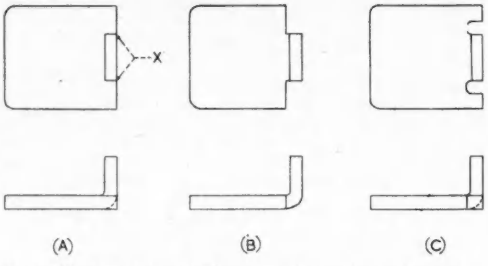


Fig. 3. **Designs (B) and (C) are easier to form than the design shown at (A).**

In the small-lot stamping process, 90 degree bends are made on stock dies. No tooling costs are involved, particularly when the bend extends the full width, or length, of the part. But if the bend extends only part way across the blank, Fig. 3 (A), difficulty and additional tooling will be encountered, unless the design is made to avoid them. Forming such a part requires not only that the material be bent but also that it be sheared loose at the edges marked X. Therefore, a special forming tool has to be made for each bend of this design. In addition, the material adjacent to the sheared edges must be held tightly, otherwise it will pull up with the formed portion, tear, and leave an unsightly appearance. Figs. 3 (B) and (C) show designs that can be formed with standard 90 degree tools. Normally, the notches on either edge of the formed portion, Fig. 3 (C), are made equal to the thickness of the material, or not less than $\frac{1}{32}$ in. for thin materials.

When designing parts with 90 degree forms, the inside height of the formed portion should always be considered. The outside surface is under tension and has a tendency to shorten the outside height. If the total height of the formed portion is small, the edge may be left non-parallel to the base, Fig. 4 (A). The minimum height for parallelism is indicated in Fig. 4 (B). If the non-parallelism of shorter heights is objectionable, then additional material must be allowed for in the blanking die and the formed portion trimmed to the required height after forming.

SPRINGBACK.

Practically the same conditions apply to common U-shapes that apply to 90 degree bends, but spring back of the material must be allowed for. Soft materials generally take sufficient set in the forming die to give little trouble from spring back. Materials in which the temper exceeds half-hard generally will produce an open-U, as indicated by the dotted lines of Fig. 5 (A). To get formed parts having parallel legs at 90 degrees to the base, usually requires a re-hitting operation. The cost of a re-hitting die for U-forms frequently exceeds that of the initial forming die. The specification of materials that have little or no spring back, therefore, is often desirable.

Holes can be pierced most economically in the flat blank of a U-shape stamping prior to forming, but shifting of the blank during the forming operation may then affect the alignment of the holes in the legs of the U-shaped part. To avoid this a pilot hole can be pierced in the base of the U simultaneously with the piercing of the other holes, Fig. 5 (B). The pilot hole serves as a means of positioning the blank and prevents shifting during the forming operation. If a pilot hole is not permissible, then the holes in one leg can be pierced before forming, and will be used after forming to position the U-shaped piece for piercing the hole, or holes, in the other leg. The additional tooling and labour make this method less desirable.

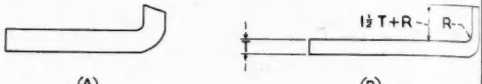


Fig. 4. **(A) Formed portion that is too short to yield a top edge parallel with base. (B) Minimum height if edge is to remain reasonably parallel to base after forming; a greater height is recommended if parallelism is important.**

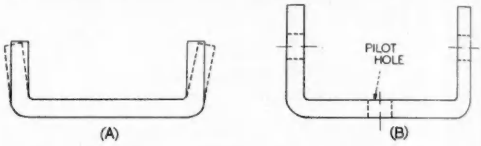


Fig. 5. **(A) Springback is likely to cause an extra forming operation for materials with tempers exceeding half hard. (B) A pilot hole can be used to position the blank of a U-stamping when holes in the legs must line up.**

Lancing operations cause more tool trouble than the other operations because the tool has to shear and form the material simultaneously. Exact alignment of the punch and die is then required to avoid burrs on the lanced edges, and to avoid breakdown of the tools. Besides alignment of the tools, the temper of the material being fabricated is also important. If the material is not soft enough to form satisfactorily, ragged fractures will develop at the forming line, that is, at the position marked X in Fig. 6 (A). If a notch equal to the thickness of the material and not less than $\frac{1}{32}$ in. is pierced around the portion to be formed, then forming the ear with a standard 90 degree V-die is a simple matter.

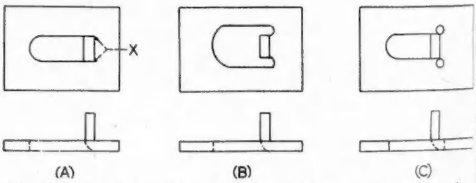


Fig. 6. **The design shown at (B) or (C) is preferred to the design shown at (A) for ears or stops on stampings to prevent ragged or torn edges.**

If notches are not permissible for other engineering reasons, piercing holes in the part of the forming line is helpful, Fig. 6 (C). Such holes relieve the forming stresses and prevent cracking. After the holes are pierced, the ear can be lanced in the regular manner. Ears of this type frequently serve merely as stops or trip dogs. Accordingly they are comparatively short. The proportions already described of 90 degree V-bends are satisfactory for the forming operation. If short heights are required, it may be necessary to allow extra material, which can be cut off to the desired height after forming.

EXAMPLE.

Economy of the small-lot stamping process can be illustrated by comparing the costs of producing the

same part by different methods. The small bracket, Fig. 7 (A), was originally designed as a casting because the quantities were small. The breakdown of the cost of the first 200 cast pieces was as follows :

ITEM FOR CASTING.	Cost.
Wood pattern	$10·00
Milling fixture (for finishing bottom)	22·00
Drill jig (three holes)	18·00
Tool cost	$50·00
200 castings	9·50
Milling operation	7·00
Drilling	5·00
Cleaning and painting	3·50
Production cost of 200 pieces	$25·00
Total cost of first 200 pieces	$75·00

If the designer had specified a stamped part, Fig. 7 (B), for production with permanent tools of conventional type, the breakdown of costs, according to the designer's estimate, would have been as follows :

ITEM FOR CONVENTIONAL STAMPING.	Cost.
Compound blanking and piercing die (including extrusion)	$125·00
Forming die	65·00
Total cost	$190·00
Blank, pierce and extrude 200 pieces	2·25
Forming	1·75
Material for 200 pieces	1·20
Cadmium plating	1·85
Production cost for 200 pieces	$7·05
Total cost of first 200 pieces	$197·05

Comparative costs of making stamped part on small-lot equipment were as follows :

ITEM FOR SMALL-LOT STAMPING.	Cost.
Blanking die	$16·00
Piercing die (including extrusion)	6·00
Forming die, standard equipment, which, like machine, is not charged to piece	0·00
Total cost	$22·00
Blanking 200 pieces	4·20
Pierce and extrude	5·60
Forming	3·50
Material for 200 pieces	1·20
Cadmium plating	1·85
Production cost of 200 pieces	$16·35
Total cost of first 200 pieces	$38·35

After the first units were assembled, two design changes in the part were considered desirable. One was a change in contour, which was made for a tool charge of $16·00. The other was the size of the holes, which was made for an additional charge of $1·50. To have made these changes in the stamping for manufacture by one of the conventional methods would probably have required replacement of the blanking and piercing tools.

If the comparison is based on production costs alone, the small-lot stamping process is between the other two. Regardless of the quantity, therefore, the casting could not be made at less cost. The casting is also a heavier part than the equivalent stamping. A quantity of about 4,000 pieces is required if the lower production

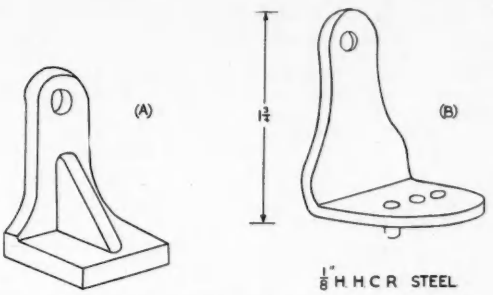


Fig. 7. (A) Small bracket made as a casting. (B) Same part weighing considerably less, made as a stamping from half-hard corrosion-resistant steel.

costs of the conventional stamping method are to offset the higher tooling costs.

In practice the quantity of parts made by a set of tools in small-lot service is limited to 8,000 or 10,000 pieces. There are two reasons for this limitation : (1) larger quantities generally can be made more economically by conventional methods, as illustrated in the foregoing cost comparison ; and (2) tool wear becomes noticeable, although the tools on some forming, drawing and extruding operations can be used for as many as 15,000 or 20,000 stampings before they fail to produce parts of acceptable accuracy.

NEW EQUIPMENT.

Recently a new blanking technique called the " cushion blanking die " was developed. Conventional presses can be set up for using this new patented equipment. The same type of short run tools are used but the cushion blanking die has made possible an increase in the speed of production by 500 per cent and the die life has been doubled.

This new machine is used for blanking out metal stampings only. The same kind of tools are used but the punch and die are inverted so that the punch is fastened to a special bolster plate and the die is suspended above it on a pneumatic cushion. The cushion is also provided with an ejector, which is operated by a cam fastened to the press crank for ejecting the stamping from the die. A unique adjustable automatic stop permits the operator to run the press wide open on this blanking operation.

A new piercing press, developed during the past two years, has been specially designed for making short run metal stampings. The press is automatic in that it is tripped by contact with the work, which allows the operator to use both hands freely in placing the parts in the press and taking them out of it. Two, three or four of these presses can be grouped together so that several holes of different sizes can be pierced with one handling of the part. This has eliminated the extra handling of the parts, which was the greatest factor in determining the cost of piercing holes by the short run method.

ADVANTAGES.

To illustrate clearly the advantages of the small-lot stamping process it is worth while considering some of the problems that confront a manufacturer in getting a new machine product on the market. Next to initial cost of production probably the most important problem is the element of design change. Even with extremely carefully designed machines or products, minor changes, such as the relocation of holes to facilitate assembly, adjustments to provide greater or less clearance between moving parts and other alterations are always possibilities.

When circumstances are such that a complete redesign makes new tools necessary, the temporary dies are much less costly to discard than conventional dies. Moreover, standard tools for forming and other operations can be laid aside for use in the fabrication of other stampings.

Of equal importance in deciding on the type of tooling to make a part is the quantity ultimately to be required. On some special machinery or equipment, the manufacturer knows in advance that the quantity will be limited and is guided accordingly. Common practice in this case has been to make many parts from cast iron because the tooling for conventional stampings is expensive. The small lot stamping method has eliminated this factor.

There are, however, a great many instances in which the number of pieces ultimately to be needed is not known until after a limited quantity have been put to test by the users. It is here that well-designed products sometimes fail for one cause or another. At other times the designer of a machine tries to embody too many improvements simultaneously, making the product impractical until design changes are made

Hand-made samples, in the past, seem to have been the answer to the question : How can a small quantity be made of all the stampings required, without going into a lot of tooling expenses ? These hand-made samples still left something to be desired. They were expensive and no two were exactly alike. They did not fit or perform in the same manner as die cut pieces. These are typical of the reasons why designers and manufacturers in practically all branches of industry are turning towards the making of metal stampings by small-lot technique.

U. S. A.

Late Trends in Piston Rings with Special Application to Diesel Engines

By H. G. BRAENDEL. (From *Diesel Power and Diesel Transportation*, Vol. 25, No. 6, June, 1947, pp. 37-41, 11 illustrations.)

THE piston ring was subjected to a very intensive development programme during the war years. It was found that the ring developments which were produced at great expense to provide satisfactory operation of high-output aircraft engines can be very satisfactorily applied with very little modification to all other internal combustion engines, such as those of the automotive and Diesel fields. The object of this article is to review briefly these general developments and then discuss some of the problems which are peculiar to various types of Diesel engines.

The discussion of rings will be divided into two main categories, viz. : compression and oil rings, and will be followed by a general discussion of the improvement of ring materials and ring coatings and some special types of rings employed in Diesel engines, as well as improvements obtained in cylinder surface finishes which are directly related to the successful operation of the piston rings.

COMPRESSION RINGS.

Prior to the war, practically all compression rings were of the plain type, with a rectangular cross section and parallel sides. They performed satisfactorily in relatively low output engines, but permitted scuffing and excessive blow-by whenever an engine was subjected to high loadings. It was found that when a twist was imparted to the ring, its performance in regard to blow-by control and life was improved considerably. The twist was produced by removing metal either at the upper corner of the inside diameter, or at the lower corner of the outside diameter, This unbalance in the section causes the ring to twist when it is compressed to cylinder size in such a way that it contacts the upper piston land close to the O.D. and the lower piston land close to the I.D. The ring also contacts the cylinder bore at the lower edge. This line contact at a high unit pressure produces a much better seal against the passage of gases around the back of the ring. The initial line contact at the lower edge of the face also produces a better seal between the ring and the cylinder. In addition, it allows the ring to seat or wear-in quickly and produces a certain amount of oil control action during the seating period. Twisted rings, therefore, are replacing plain type rings in most automotive installations and are starting to be used in the smaller high-speed four-stroke cycle Diesel engines.

WEDGE-TYPE RINGS.

In some installations ring sticking is a serious problem. It occurs mainly under conditions of high temperatures and high pressures which are experienced both in aircraft and Diesel engines. In such installations a wedge-type ring has been found to eliminate sticking when all other means, such as increasing the side clearance, have failed. The optimum included angle for wedged rings has been found to be in the neighbourhood of 15 degrees. This ring prevents sticking mainly because wear on the face of the ring will produce side clearance in the groove thereby constantly compensating for the accumulation of carbon and lacquer which are the primary causes of ring sticking. Although most manufacturers still use a plain wedged ring, or one without a twist, this ring will also perform better in regard to blow-by control by providing it with a bevel at the upper I.D. and twisting it in the same manner as the parallel-sided twisted rings.

RING WIDTH.

Tests in all types of engines have shown that the performance of compression rings in respect to sealing and freedom from scuffing improves as the width of the ring is reduced. In a case of very high specific output aircraft engines, it was found necessary to use $\frac{1}{16}$ in. wide rings for bores between 5 and 6 inches. In conventional automotive and Diesel engines there has been a definite trend in the reduction of ring widths during the past twenty years. This is now being carried over to heavy Diesel engines, especially those used in railroad locomotives. For instances, the 9 in. bore rings used in the American Locomotive Diesel have a width of only $\frac{1}{4}$ in., Diesels of the same size but of older design still have rings with a width between $\frac{1}{4}$ and $\frac{3}{8}$ in.

MATERIALS FOR COMPRESSION RINGS.

Ring materials have been developed with the object of obtaining greater strength and greater tension without sacrificing wearing ability. The decrease in ring widths requires greater strength to avoid breakage under heavy combustion loadings. Furthermore, tests have generally indicated that the employment of a higher unit pressure will produce better sealing and longer life. Metallurgical research and the development of centrifugally cast material with carefully controlled

heat treatments has led to ring cast irons with physical characteristics approaching those of steel. Changes in alloying have made it possible to produce materials of varying qualities so that a material can be selected with the desired characteristics for each application. The general result of this work is that all material used in piston rings is stronger than that produced before the war and will give longer life in addition to better performance.

OIL-CONTROL RINGS.

The improvements in the design of oil-control rings are largely a result of the increase of the physical characteristics of the materials. Tests have shown that the oil controlling ability of a ring is directly proportional to the unit pressure employed on the cylinder contacting lands, all the other factors being equal. Changes in oil ring design, therefore, have exploited the possibilities of better materials to provide both improved oil controlling ability and a much longer life, which in the case of one industrial engine, was of the order of 500 per cent. The better materials also permitted the use of wider and longer slots which have provided longer life in such installations in which formation of varnish and carbon deposition causes plugging.

RING COATINGS.

Ring coatings have been developed for two different purposes. The more common type of coating is the one provided for quick seating and wearing-in ability of the ring.

All rings pass through a critical stage when the engine is first operated. The ring must seat or wear-in fast to provide a complete seal between its face and the cylinder wall. If it fails to do this, blow-by occurs which will errode the surface, making subsequent sealing very difficult. After this initial seal is provided, the ring must wear very slowly, so as to provide a long life. Quick seating coatings are divided into three classes : the phosphate coatings, the oxide and graphitic coatings, and the soft-metal coatings such as tin, cadmium, or lead plate.

The phosphate coatings give the cast iron a rather hard surface with some oil-holding ability. This layer of iron phosphate must be broken before scuffing can occur. Scuffing and resulting scoring will take place during a temporary period of marginal lubrication. The fast relative motion between piston and cylinder over a temporary dry spot will heat the dry section of the ring and cylinder metal to their melting temperatures, and local welding will take place. Soft metal coatings such as 0·0003 to 0·0005 in. plate of tin, cadmium or lead will melt under scuffing conditions and the molten metal will serve as a temporary lubricant for the iron.

The oxide and graphitic coatings give the ring a highly etched surface providing many surface irregularities which are filled with a mixture of iron oxide and graphite. This material soaks up the oil and carries the ring over temporary dry spots of much longer duration than either the phosphate or plated coatings.

The second type of coating, which has been specifically developed to provide long life under either extremely high loadings or abnormal dusty conditions, is the chrome plating of rings. Chrome-plated rings were developed in a very short time during the war to meet the difficulties of military engines exposed, in desert warfare, to an abundance of very fine and sharp dust, which reduced the life of aircraft and ground vehicle engines to between 12 and 50 hours under these conditions. Although the efficiency of air-cleaners was raised from 95 to 99 per cent, the engines were still short-lived because the 1 to 2 per cent of dust which they digested was still excessive. The use of chrome-plated rings in the top groove increased the engine life under such conditions to between 300 and 400 per cent. Subsequent tests have indicated that a large benefit in engine life can be obtained with the top rings chrome-plated in engines operating under fairly high specific loadings or under high operating temperatures. Because of the relatively high cost of chrome-plated rings, their use cannot be justified economically for installations in which unplated rings give satisfactory service, for instance in engines in which bearings or valves require servicing before the conventional rings need replacement.

SPECIAL PURPOSE RINGS FOR DIESEL ENGINES.

A relatively recent development made specifically for two-stroke cycle Diesel engines is the filled ring. The two cycle engine which is valved by piston ports presents a serious problem in cylinder lubrication for the top ring belt. These engines operate under marginal lubrication conditions during a large percentage of the time, and it has been found necessary to develop compression rings of the filled type to obtain satisfactory engine performance and life. One type is a special tin-grooved compression ring in which the groove is only partially filled with tin. This has been found to meet the requirements of high temperature operation under marginal lubrication conditions. The grooves fill with carbonaceous matter which absorbs oil, thereby helping this ring to operate satisfactorily over dry periods. In emergencies the tin will melt and serve as a lubricant. The second type of filled ring is one which does not employ a soft metal, but a chemical filler which is baked into the grooves. This filler is porous and will absorb large quantities of oil. During periods of marginal lubrication, the filler will release the oil and during periods in which surplus oil is available, it will reabsorb the lubricant.

EXPANDER RINGS.

During the war there was a large increase in the use of expander rings in service operations. This was partially the result of the scarcity of replacement parts such as pistons and liners which induced many operators to keep their equipment rolling by using expander ring sets with partially worn sleeves and pistons. The experience most operators had during this period with expander ring sets showed that even in heavy duty engines, satisfactory operating life could be practically doubled before reboring or resleeving became necessary.

Expanders have, of course, been used rather widely in original installations with very successful results. The two-piece expander-type oil-control ring which was developed by Wilkening in 1938 has remained in production during the past nine years with an excellent service record. Although numerous other rings have been tested for this application, none has been found to give better performance in regard to oil controlling ability and life than this design. Expander-type rings will continue to be used in installations requiring higher tension than can be obtained with the best cast-iron materials, and of course, in service sets in which the expander permits a flexible and conforming ring to be used which will follow the irregularities of a worn cylinder.

SEAL-CUT RINGS.

Tests run on a number of different types of engines have served to clarify the possible effect of ring gap on blow-by and oil consumption. In high-speed automotive and Diesel engines, the operating gap is relatively unimportant. In cylinders of 4 to 5 in. diameter, there is no noticeable drop in power or performance until the operating gap exceeds 0·060 inch. This does not mean, of course, that it would be advisable to install rings with such wide gaps when new, since it is preferable to fit rings with the smallest allowable gap to assure a long life. In case of oil control rings the gaps may be still

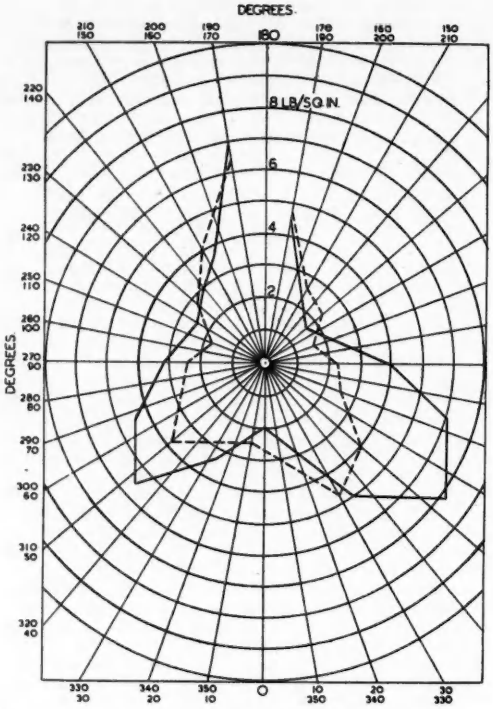


Fig. 1. Radial pressure of ring made by the casting-out-of-round method. Solid line indicates pressure before engine test. Dotted line is reading after engine test.

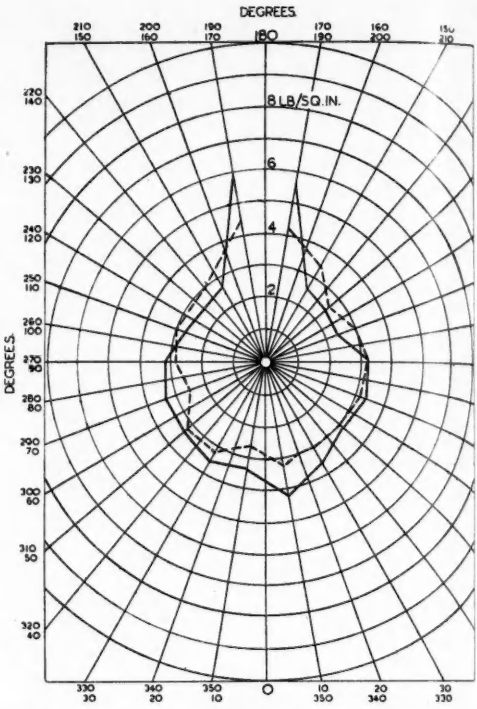


Fig. 2. Radial pressure of ring made by the heat-shaping process. Solid line is reading before engine test, dotted line is reading after engine test.

Figs. 1 and 2. Comparison of radial pressure distribution of rings made by different processes.

larger without having any apparent effect on the oil performance of the engine.

In slow moving large bore diesel engines, however, running at 100-300 r.p.m., there is a measurable drop in performance if large gaps are used or if the gaps are allowed to increase due to ring wear. In such installations, it is preferable to use a ring with a seal-cut construction in which the gap is completely sealed until a really excessive amount of face wear has taken place. Rings with diagonal cuts or step cuts show practically no advantages over the straight cut rings, since they do not provide an effective seal at the gap.

CYLINDER FINISHES.

The cylinder finish, which has an important influence on the success of a ring installation, was often made as smooth as possible with the expectation that this would make for the longest life and most satisfactory performance of the installation. Extensive research has proven this to be erroneous. A series of tests has shown that the most desirable surface for cylinder bores is an interrupted one, consisting of small flat plateaus separated by deep channels. It was found desirable to have the channels as deep as 0·001 in. and the plateaus approximately 0·005 in. wide. In this surface, the channels or grooves are filled with carbonaceous matter in a short period of normal operation. This material absorbs oil which it will release under the inducement of higher temperatures when needed. Since cylinder ring wear takes place only when the oil film breaks down, the presence of this oil reservoir in the entire surface of the cylinder reduces the periods of improper lubrication to a fraction of their normal duration. Consequently, such interrupted surfaces properly produced have increased engine life under severe operating conditions by as much as 200 per cent in very high specific output engines. The additional advantage of the interrupted surface is its scuff and score impeding action. Should foreign matter, such as a particle of abrasive dust, become interposed between the face of the ring and the cylinder, its tendency to score would be practically restricted to the passage over one plateau. After this, the particle will probably drop into a groove where it ceases to disturb the operation. This has been proven by running tests with controlled dust admission ; during these tests the interrupted surfaces have given much longer life.

The most effective means of providing such a surface in practice is by scratch honing. Cylinder bores are first honed relatively smooth with a 300 to 400 grit stone, then given eight to twelve strokes with a turning motion and 36 grit stones under heavy pressure to provide a diamond-shaped 45 degree pattern. This operation will provide gouges cutting the surface as much as 0·0005 in. deep. After this, the cylinder is polished with a 400 or 500 grit stone to remove all the upset metal and ragged edges. It is essential that it is then carefully washed to remove all loose particles from the grooves.

This process may still be too involved for some operators and could not be accomplished without the use of a heavy honing machine. It is possible, however, to approach this type of finish in rebuilding engines by using a rather rough honing stone for a short period and finishing with a very fine stone without attempting to remove the rough honing marks. This type of cylinder finish will provide quick seating of the rings and improved operation over long periods of time.

The Use of Oxygen in Metallurgical Furnaces

By V. A. Mozharov. (From "*Kislorod*," No. 1, 1946, pp. 1–14, 1 illustration.)

The following is an abstract from a paper and subsequent discussion in the U.S.S.R. Institute of Oxygen. The use of oxygen in connection with Open Hearth furnaces, of topical interest in the U.S.A. and in Great Britain, has not yet become commercial practice in Russia; but the discussion revealed that her highest authorities, including the world-famous oxygen and atomic expert Professor Kapitsa, have been studying the problem. The bulk production of oxygen by Professor Kapitsa's "turbo-generator" probably makes the use of great quantities of oxygen both attractive and economically possible.

1. The Characteristics of a Gas-fired Furnace Flame (with special reference to a Siemens-Martin Furnace).

Combustion takes place along the boundary edge of the gas stream which is wide and thin at the inlet port, and thereafter, spreads out sideways rapidly and leaves the furnace as a thin layer of unburnt gas. Combustion must be preceded by the gas mixing with the surrounding medium and it is influenced by the fact that at the inlet port the "surrounding medium" is almost pure air and at the outlet end of the furnace it is almost entirely "products of combustion."

The principal factor determining the amount of fuel that can be burnt in a given furnace with a given amount of excess air is the calorific value. The higher the calorific value the smaller the amount of gas. Tests with a typical furnace yielded a fairly accurate formula :

$$\text{Quantity of fuel} = \frac{\alpha}{\sqrt{\text{Cal. value}}} - b$$

This gives a series of curves for different values of α (the coefficient of utilization of air) and is the basic formula used in the calculations discussed below. The formula does not apply generally in any direct manner but can be modified to apply to any furnace.

2. The Thermal Effect of Using Oxygen.

As we replace nitrogen by oxygen the volume of the products of combustion per unit of gas burnt will be reduced, and thus there will be more heat per unit volume of the furnace gases and per unit volume of the combustion chamber. The first effect is a greater intensity of heat obtained from any given gas and therefore a possibility of using fuel gas of poorer quality.

Also, the increase of oxygen content in the furnace gases permits a greater amount of fuel to be burnt and, with a given calorific value of gas the amount of fuel burnt will increase as the oxygen content of the air stream is increased up to a maximum if pure oxygen is used. Thus the intensity of heat in the furnace will be increased for this reason also.

If gases of variable calorific value are used, variation in oxygen content of the air stream can be used to regulate the process of combustion, but this is not a very important consideration as sudden variations in gas quality are not often met with.

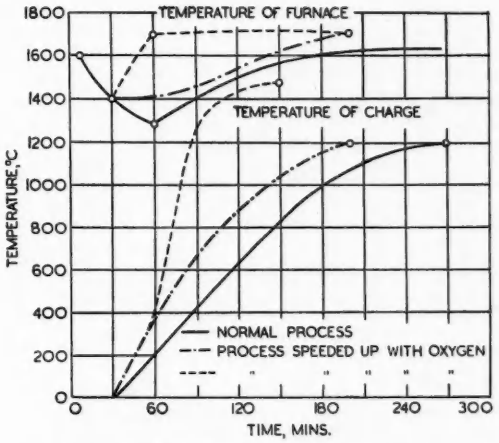
3. Practical Application to Open Hearth Furnaces.

We can consider the effect of oxygen from several points of view, namely :

(a) Speeding up of an existing process.
(b) Rendering the construction of new furnaces simpler and less expensive.
(c) Effecting savings by the use of lower grade gas.

In all cases our aim will be to reduce fuel consumption to a minimum.

Temperature conditions inside a modern open-hearth furnace are limited by the refractory qualities of the lining and the outgoing gases must not be raised above the present accepted maximum of 1,650 deg. C. Nevertheless, there is much room for improvement in the temperature regime and in the speeding up of the process because at present the temperature in a furnace varies a great deal.



The accompanying illustration shows how furnace temperatures usually vary to-day and indicates how the introduction of oxygen can modify the process to give much higher temperatures during an important part of the cycle which will melt the charge more quickly. It will be noted that at present when a charge is introduced the temperature falls appreciably, due to the cooling effect of the charge itself and to the frequent interruption of gas supply for inspection purposes. Thus, however good the gas, it is found impossible after introducing the charge to revert to the maximum furnace temperature.

But if oxygen is introduced, the intensity of heat can be rapidly increased and the maximum temperature can be re-attained. It is calculated that the time taken to melt the charge in a modern furnace of 200 ton capacity can be reduced by approximately 2 hours, which is equivalent to approximately 20 per cent increase in productivity. If, in addition, the use of oxygen should render the slag less foamy one may expect some further speeding up of the process—but this can only be verified experimentally.

The oxygen content of the oxygen enriched air stream and the length of time during which enrichment is necessary depends on the calorific value of the gas. The higher the calorific value the shorter the period of oxygen admission. For average conditions oxygen is necessary only during the charging and heating-up periods, whereas with poor quality gas its use would have to extend to the melting process. The minimum requirement is that the gas should be of a quality sufficient to maintain the temperature of the furnace during the "boiling" of the metal without recourse to oxygen. This is relatively simple and in modern furnaces often involves an actual reduction in the gas quantity to prevent over-heating. With gas of this minimum calorific value, the process would require oxygen admission throughout, right up to the commencement of the boiling stage.

Considering, as a typical example, a 185-ton furnace of 5,400 cu. ft. capacity, with a normal output of 18·5 tons per hour, its performance with gas of various calorific values and with various amounts of oxygen

enrichment has been worked out. A typical result of using the optimum amount of oxygen (for instance, 1·86 cu. ft. of oxygen per cu. ft. of gas with a calorific value of 73 calories per cu. ft., or 2·28 cu. ft. when the calorific value is 85) are that the productivity rises by about 23 per cent, or by $4^1/_2$ tons per hour, at the cost of some 1,500 cu. ft. of oxygen per ton of steel. The time per cycle of the process is reduced by about 1 hr. and 50 min. Another way of looking at this result is that each extra ton of steel produced requires an expenditure of 8,000 cu. ft. of oxygen.

If more oxygen is used than the calorific value of the gas justifies, the " cost per ton " rises. For example, if the calorific value of fuel is down to 63 and the oxygen is maintained at 1·86 cu. ft./cu. ft. of gas as in the previous example, the gain in productivity is only 2·27 tons per hour at a cost of 12,500 cu. ft. of oxygen per extra ton produced.

4. Influence of Furnace Capacity and Composition of Charge.

As the rated capacity of the furnace (in tons) increases, its cubic capacity also increases, but more slowly. In small furnaces, say of 40–50 tons, it works out at 39 to 44 cu. ft./ton, while in a modern 300 ton furnace it might be only 18 to 21 cu. ft./ton. Thus the combustion space per ton is halved, although it plays a vital role in determining the productivity of the furnace.

The author's experiments show that the amount of gas which can be burnt in a furnace is directly proportional to its combustion space if the height of the chamber is kept constant. When the height is increased, however, combustion does not increase proportionally. Thus in the general case of increasing furnace capacity, with a corresponding increase in all the dimensions the amount of gas that can be burnt increases almost, but not quite as fast as the volume.

This explains why the trend towards larger furnaces is accompanied by a drop in heat production per ton of charge per hour and the consequent lengthening of the time of the process.

The proposed use of oxygen, which permits the burning of gas of a higher calorific value in a greatly reduced space, should therefore prove particularly important when the combustion space per ton of charge is small, i.e., in the larger and more modern furnaces. It will also simplify problems of roof design in furnaces of extra large capacity.

However, whilst it is believed that the new process will be most successful for large processes, it is recommended that trials should first be made on a small scale. A small furnace can very well be used as a scale-model for a larger one by increasing the weight of charge far above the normal, thus reducing the volume of combustion space per unit weight of charge.

The calculations we have made are all on the basis of a charge containing 65 per cent of pig iron and 35 per cent of steel scrap. With a higher percentage of scrap the charging and heating up stages take up a longer time during the cycle and therefore there is more scope for the use of oxygen and greater advantages from its use may be expected.

The calculations are also based on the assumption that the speed of burning, i.e., the speed of propagation of the flames, will remain constant. There is little data on this aspect but while it appears to be almost constant in ordinary furnace conditions one may expect some speeding up if oxygen is introduced. This would further improve furnace efficiency. Experimentally derived data in this connection is particularly necessary as the speed of combustion determines the velocity and cross-sectional area of the gas jet required and hence the size of the gas inlet aperture, which at present is found empirically.

5. Scheme of Operation Using Pure Oxygen Alone.

If a furnace were run entirely on oxygen the required temperature could be obtained on the hearth without recourse to regenerators and this would simplify the system enormously. A chamber with gas and air inlets at one end and an outlet duct at the other is all that would be needed and no arrangements for reversing the gas flow would be necessary.

The products of combustion can be used in two ways :

(a) After their excess heat has been utilized for steam raising or other purposes, they can be used, with the addition of oxygen, in a gas producer working on solid fuel. A certain proportion in excess of producer requirements would be wasted.

(b) The gases can be divided into two unequal portions, the smaller of which would be mixed with the fuel gas and return to the furnace whilst the larger would be utilized for steam raising, etc.

Thus, so far as the furnace is concerned, the first alternative would utilize the products of combustion to generate fresh fuel gas from solid fuel, whilst in the second the gases would be short circuited back to the furnace at 1,500–1,550 deg. C.

An obvious adverse factor in the functioning of a furnace using pure oxygen would be the presence of nitrogen " ballast " in the fuel gas itself. Thus, technically speaking, it is wrong to base such a process on the usual type of fuel gas. But because, in a steel works, the cost of blast furnace and coke oven gas is low their use may prove to be economically sound even with pure oxygen.

The use of high-grade, low-nitrogen fuels, such as crude oil, town gas, and natural gas, is in any case not necessary. They have the advantage of simplifying an installation to the limit, as explained later, but low grade fuels can also be made eminently suitable, provided that they are gasified without the admixture of air.

To obtain suitable gases from solid fuels it is necessary to run the producer plant on furnace gases instead of an air-steam blast, so that a closed gas circuit is formed and nitrogen is excluded.

Furnace gas contains a large amount of CO_2 and its conversion to CO absorbs a great amount of heat. To maintain the required temperature in the producer, therefore, it is necessary to mix with furnace gases a certain amount of oxygen.

A producer run on these lines would be able to provide gas of a calorific value up to 74 calories/cu. ft. and it is estimated that it would utilize two-thirds of the total products of combustion or, say, 70 per cent of the available gas after deducting losses through the furnace openings. Thus only 30 per cent would be allowed to go to waste through the smoke-stack.

The gases are under vacuum between the furnace and the producer plant so that there will be some leaking-in of air. However, the nitrogen which is therewith admitted is no more harmful to the final product of the gasification process than the CO_2 and so long as the leakage does not exceed 10 per cent it will not be detrimental.

In order that the temperature in the furnace should not exceed its permissible maximum the calorific value of the gas should be about 32 calories/cu. ft., but it is also possible to use gas of higher calorific value and to reduce the temperature by admitting less oxygen. It is estimated that if the calorific value of the gas is 68, a correct temperature will be obtained with 30–35 per cent incomplete combustion ; and if 70 per cent of the products of combustion are used again the loss of heating value which this procedure involves is not very serious.

The system outlined can be applied to any size of furnace ; there are no theoretical limitations. It can also be applied to all types of furnaces, namely, those for the manufacture of carbon and alloy steels, iron and

steel foundry work and non-ferrous metals, and will be able to compete on equal terms with all kinds of electric furnaces.

As the proposed heat cycle does not include regeneration it is essential to make use of the physical heat contained in the outgoing products of combustion, which, with gases at 1,650–1,700 deg. C., will be about 60 per cent of the total heat generated in the furnace. In large metallurgical works this can be used for steam raising. In foundries which do not operate in conjunction with a blast furnace the hot gases can be utilized to preheat and melt pig iron and scrap.

Approximate calculations show that the use of oxygen will speed up the operation of large furnaces by up to 25 per cent. For smaller installations one can take into account the pre-melting of the charge and in that case the speed-up can be 30 per cent and more.

An advantage of the system is that solid fuel of very low calorific value can be used in the producer. A disadvantage is the necessity for complicated arrangements to dispose of waste heat, though these do not detract from the essential simplicity of working of the furnace.

The closed cycle results in gradual accentuation of the sulphur content in the gases, and it is essential therefore to choose low-sulphur fuels or to take steps to remove the sulphur from the gases.

Heat consumption per ton of output is greatly reduced by the use of the oxygen-fed closed cycle. For example, a 200 ton furnace will require $0{\cdot}5 \times 10^6$ calories per ton of output, while an ordinary modern Siemens-Martin furnace working with similar gas would require $0{\cdot}9 \times 10^6$ calories. Waste heat recovery in a boiler has been allowed for in both cases.

A similar calculation for a 10-ton furnace working on crude oil shows that heat consumption would be reduced by the use of oxygen from $1{\cdot}25 \times 10^6$ to $0{\cdot}55 \times 10^6$ calories per ton.

The reasons for this increase in thermal efficiency are :

(a) Only 30 per cent of the products of combustion are allowed to escape during each cycle, i.e., the loss on that score is three times smaller than from a furnace which is not oxygen-fed.

(b) Waste heat recovery can commence at 1650–1700 deg. C. instead of the usual 550–700 deg. C. Thus heat recovery is increased 2·5 to 3·5 times.

(c) The generator gas has a greater heat value than the usual type of fuel which results in improved efficiency.

Furnace control is very much simplified under the closed cycle system. It is reduced to regulating the amount of fuel gas admitted and to adjusting the admission of oxygen accordingly.

RUSSIA

Use of Hollow Charges in Mining

By L. F. Volochkov. (From *Gornii Zhurnal*, No. 6, 1946, pp. 19–20, 2 illustrations.)

The Hollow Charge principle was first experimented with in Russia in 1925 by Professor Sukharevsky, who found that lead plates could be pierced more effectively by explosive charges with a drilled-out end.

In 1943 the author applied it to mining work and carried out a number of large-scale practical tests in the Spassk gold mines to determine the advantages gained, while a colleague conducted a similar series of tests in the Mulchinsk mines.

At Spassk the rock was scheelite ($CaWO_4$), a hard rock. Normal methods of drilling and firing were used, and hollow charge experiments were interspersed with similar tests made with similar charges without a hollow end. The same workers were employed in all operations to eliminate personal factors. The charges used were as shown in the illustration : a sheet iron cup (4) of paraboloid form was laid in the bottom of the cartridge case (5) before ramming the explosive (1) so that a hollow space was formed at (2). The explosive used was ammonite No. 2 and the hollow end was covered over with a cardboard end-piece (3). This special cartridge was followed up by normal main and supplementary charges of a standard type.

The results were as follows :

Tests.

	Total of 5 tests with normal charges	Total of 6 tests with hollow charges
Workings advanced by	19 ft.	13·7 ft.
Rock removed	830 cub. ft.	593 cub. ft.
Total length of drillings	276 ft.	245 ft.
Total weight of explosives used ..	86 lb.	78 lb.
Per cub. ft. of Rock :		
Explosives	0·104 lb.	0·131 lb.
Drillings	0·334 ft.	0·413 ft.
"Coefficient of effectiveness of drilling"	0·91	0·73

At Mulchinsk the rock was granite-porphyry, the explosive again ammonite No. 2, the cartridge 28 mm. diameter and the paraboloid cup made of paper with a diameter to height ratio of 1·5 : 1. In this case the depth of drillings and amount of charge were averaged out to be equal for "normal" and "hollow" charges and additional tests were made with single drillings.

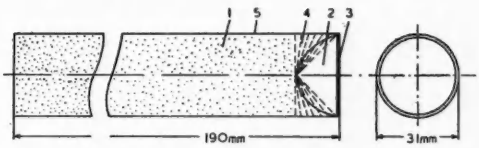


Fig. 1. **A hollow charge cartridge.**

Single-Charge Experiments (mean of 10 results with 20 in. deep blast-holes) :

	Volume of rock blasted away	Volume of rock shattered	Total
	cub. ft.	cub. ft.	cub. ft.
Normal Charge	28	42	70
Hollow Charge	42	81	123

Multiple-Charge Experiments (mean of 3 tests of each kind, each with 9 blast-holes, 3 ft. 1 in. deep).

	Volume of rock removed	Coefficient of effectiveness of drilling
	cub. ft.	
Normal Charge	96	·81
Hollow Charge	121	1·0

The following conclusions may be drawn :

(1) Use of hollow charges gives approximately 25 per cent economy of drilling with a corresponding reduction in weight of explosive.
(2) Hollow charges have this appreciable effect only on hard rock. Experiments conducted on soft rocks and frozen ground showed no substantial gain.
(3) There is nothing to choose between paraboloid cups made of paper and those made of metal.
(4) The hollow charge gives finer fragmentation of rock.

The Ball Piercing Test for Textiles

By H. SULSER. (From *Schweizer Archiv*, Vol. 13, No 2, February, 1947, pp. 45–54, 19 illustrations).

RECENTLY the burst test method has become prominent among the tests normally used for determining the strength and ductility of textile and paper fabrics. With this method the warp and the weft threads are simultaneously loaded as they are in normal service. The test results, therefore, indicate the interdependence of the two systems of threads. The orthodox tensile test requires rather elaborate preparations such as accurate cutting of specimens and careful gripping so as to avoid premature cracks. This can be dispensed with by the use of the burst test which lends itself particularly to quick routine testing.

The specimen is tightly held around a circular edge and is exposed to air or fluid pressure. Assuming spherical deformation the stresses and strains can be computed from the known pressure and the observed depth of dishing. Such calculations, however, represent only a first approximation, because the specimen, even if completely homogeneous, will not take the shape of a spherical calotte.

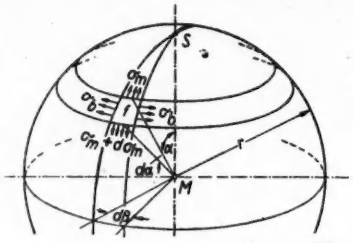


Fig. 1. **The forces acting upon the spherical surface element *f*.**

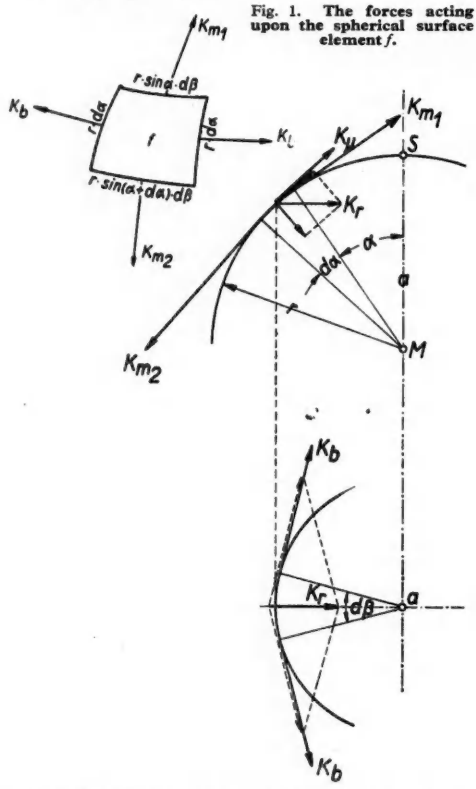


Fig. 2. **The diagram of forces in elevation and plan.**

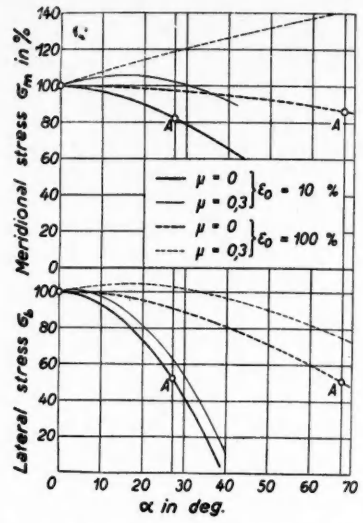


Fig. 3. **Stress diagram for the spherical calotte with various coefficients of friction μ and elongations ε_0. Stress at the apex is 100 per cent.**

With the ball piercing test a plunger with a spherically rounded head is pressed against the specimen which is tightly held at its circumference. In principle this method agrees with the burst pressure test, against which, however, it shows distinct practical advantages. There is, for instance, no need for using a rubber membrane to make the edges pressure tight, and therefore, no need to ascertain its influence by preliminary tests. The depth of deformation can easily be determined with considerable accuracy. On the other hand, the friction between the specimen and the plunger head influences the stress distribution and has to be taken into account with the ball piercing test. This fact may represent the major objection against this test method which up till now has only been little used in practice. In this article an attempt is made to determine the effect of the friction forces on the distribution of stresses and to indicate how the disturbing effects of these forces can be eliminated.

(1) THE DISTRIBUTION OF STRESSES ON THE SPHERICAL CALOTTE.

With the symbols and notations shown in Figs. 1 and 2 the following differential equation can be derived from the conditions of equilibrium :

$$\frac{d\sigma_m}{d\alpha} = \operatorname{cotan}\alpha\,(\sigma_b - \sigma_m) + \mu\,(\sigma_b + \sigma_m)$$

The lateral stress σ_b, at right angles to the meridional stress σ_m, can be expressed by :

$$\sigma_b = \bar{\sigma}_m \frac{\sin\alpha}{\alpha} - E\left(1 - \frac{\sin\alpha}{\alpha}\right)$$

Where E denotes Young's modulus. Starting at the apex S of the calotte the stresses σ_m and σ_b can be calculated and plotted for every point of the surface. Fig. 3 gives an example for various coefficients of

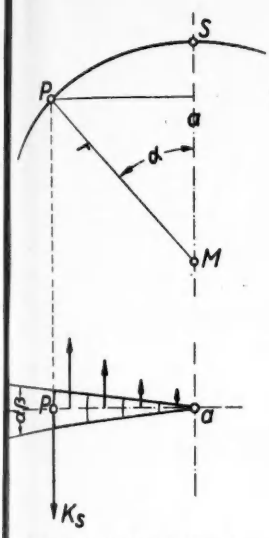


Fig. 4. **Shear forces in elevation and plan.**

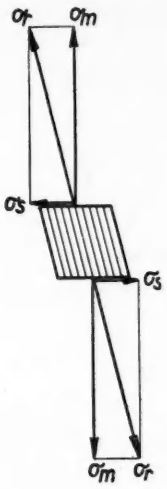


Fig. 5. **Tension and shear stresses and their resultant σ_r.**

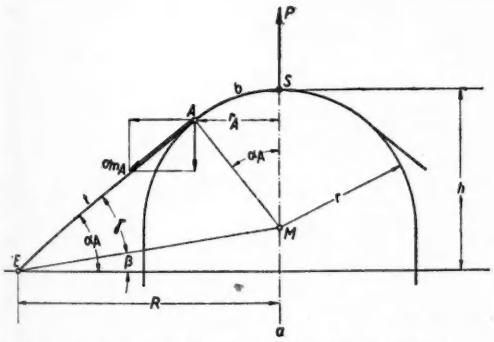


Fig. 6. **Section through the meridian for calculating the average elongation $\bar{\epsilon}_m$ and the stress σ_{mA} from the depth of deformation h and the plunger force P.**

friction μ and elongations ϵ_0 at the apex where the maximum stress will occur if frictional forces are neglected. If, however, friction is taken into account then the distribution of stresses is considerably affected and the maximum stress will be well away from the apex. The force P required for tearing the test specimen will increase with the friction coefficient. Test results are therefore largely dependent on friction between plunger and specimen. This can be avoided by axially rotating the plunger during the test. If the rotary movement is large in relation to the axial advance then no friction will exist in the direction of the meridian, but shear forces will be produced and these can be calculated from unit pressure and friction coefficient. From Fig. 4 the twisting moment caused by the frictional forces can be derived and the shear stress expressed as follows :

$$\sigma_s = \frac{\mu}{\sin^2 \alpha} \sum_0^a (\sigma_m + \sigma_b) \sin^2 \alpha \, d\alpha$$

The specimen cannot take the shear stress without deforming. The type of deformation leading to equilibrium is illustrated in Fig. 5.

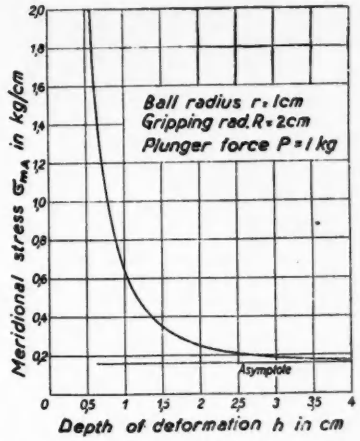


Fig. 7. **Relation between meridional stress and depth of deformation, with constant plunger force.**

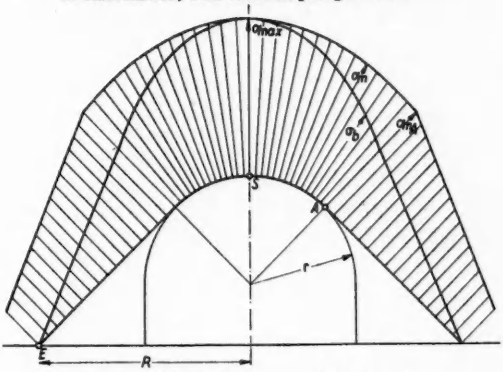


Fig. 8. **Stress distribution in a meridional section.**

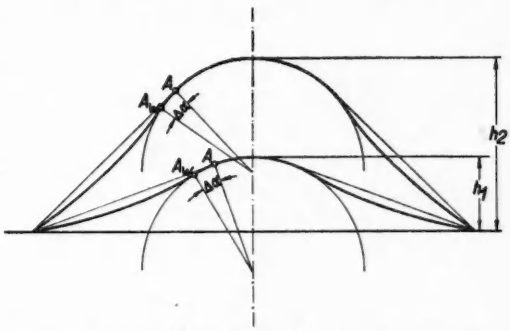


Fig. 9. **The actual form of meridional sections with different depths of deformation h_1 and h_2.**

The resultant from the tension and shear components is :

$$\sigma_r = \sqrt{\sigma_m^2 + \sigma_s^2}$$

It has been shown that the stress distribution remains approximately the same with high or low friction provided the plunger with the spherical head is being rotated during the test. Test results thus obtained are practically independent of the friction between the specimen fabric and the spherical plunger surface.

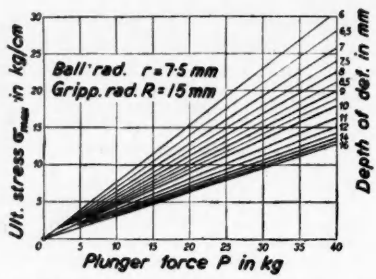


Fig. 10. **Graph for determining the ultimate stress from plunger force P and depth of deformation h.**

To simplify calculations certain assumptions are made, e.g., the validity of Hooke's law, homogeneity of the fabric, and the lateral contraction are neglected. This, however, does not affect the typical distribution of stresses.

(2) THE CALCULATION OF STRESSES AND STRAINS.

On the assumption that the specimen will deform as shown in Fig. 6 the resulting stress at point A of the plunger surface can be calculated as :

$$\sigma_{mA} = \frac{P}{2\pi r \sin^2 \alpha_A}$$

Fig. 7 shows the relation between the meridional stress at A and the depth of deformation produced on different specimens by the same plunger force $P = 1$ kg.

The meridional stress σ_m decreases in the free portion of the fabric from where it clears the ball surface at A, towards the gripping circle at E where the lateral stress σ_b is zero. Fig. 8 shows the distribution of stresses.

Certain corrections are required to arrive at exact values for stresses and strains. It is shown for instance that the fabric leaves the plunger surface, not following a tangent, but slightly curved as illustrated in Fig. 9. The angle $\Delta\alpha$ is independent of the depth of deformation and is approximately 10 deg.

Finally, a graph can be prepared as shown in Fig. 10 which allows to determine the ultimate stress from the observed test values of the plunger force P and the depth of deformation h.

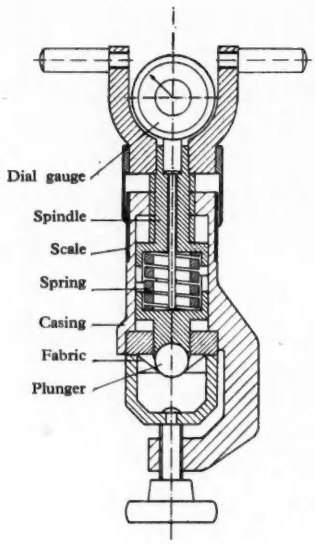
(3) COMPARISON OF RESULTS OBTAINED WITH OLD AND NEW TEST METHODS.

The ball piercing test apparatus is shown in Fig. 11 from which it can be seen that the plunger with spherical head is being axially rotated during the test thus eliminating the effect of friction on test results.

Comparison of ultimate stress values obtained by the new method with those from orthodox tests, for a great variety of textiles, allows certain conclusions, viz. :

As shown in graph Fig. 12 the ultimate stress obtained by the ball piercing test is, on an average, about 20 per cent higher than that calculated from the standard tensile test. But this increase varies for different types of textiles (marked by letters a to s). This indicates that the ultimate stress of a fabric under bi-axial load cannot be finally determined from the individual stresses in the warp and the weft threads. The same applies to ultimate elongation. The discrepancies cannot be explained as mere inaccuracies from test procedure ; figures for specimens taken from textiles of similar texture agree very well when compared with each other.

In conclusion it can be said that both the old and the new test method can be used with equal success where textiles of the same type are to be compared, as is usual in the textile trade. If, however, the properties of a specimen are to be tested in respect of the behaviour under service conditions, then the test method must be representative of the strains and stresses occurring in practice. Textiles which are exclusively or predominantly stressed in one direction only, like those used for belts, transmission drives, etc., are best tested by the orthodox tensile methods. For textiles under bi-axial load in service, the ball piercing test will produce better results.



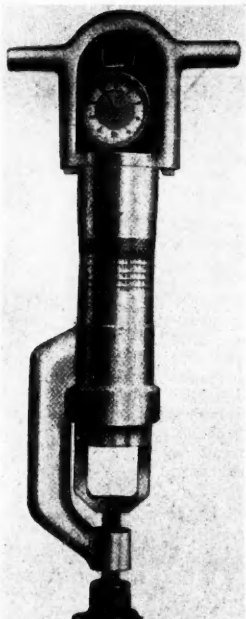


Fig. 11. **The ball penetration test apparatus, and longitudinal section.** Outside view.

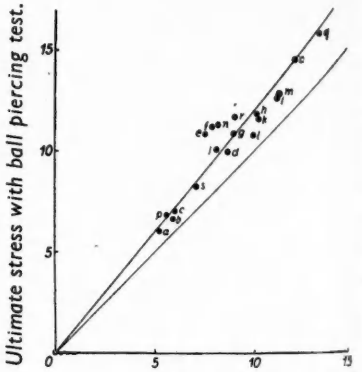


Fig. 12. **Comparison of test results obtained from tensile tests and ball piercing tests. The letters a to s refer to different types of textiles.**